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S. DEPARTMENT OF AGRICULTURE.

FORESTRY DIVISION.

BULLETIN No. 7.

FOREST INFLUENCES.

1. INTRODUCTION AND SUMMARY OF CONCLUSIONS. By B. E. FERNOW.
2. REVIEW OF FOREST METEOROLOGICAL OBSERVATIONS: A STUDY PRELIMINARY TO THE DISCUSSION OF THE RELATION OF FORESTS TO CLIMATE. By M. W. HARRINGTON.
3. RELATION OF FORESTS TO WATER SUPPLIES. By B. E. FERNOW.
4. NOTES ON THE SANITARY SIGNIFICANCE OF FORESTS. By B. E. FERNOW.

APPENDICES.

1. DETERMINATION OF THE TRUE AMOUNT OF PRECIPITATION AND ITS BEARING ON THEORIES OF FOREST INFLUENCES. By CLEVELAND ABBE.
2. ANALYSIS OF RAINFALL WITH RELATION TO SURFACE CONDITIONS. By GEORGE E. CURTISS.

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LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
FORESTRY DIVISION,
Washington, D. C., November 1, 1892.

SIR: I have the honor to submit herewith for publication a review of the meteorological observations which have been made, mostly in foreign countries, for the purpose of determining whether and to what extent forests influence climate, together with a discussion of the manner in which forests affect the water conditions of the earth and other matter elucidating the question of forest influences in general.

Respectfully,

B. E. FERNOW,
Chief of Division.

HON. J. M. RUSK,
Secretary of Agriculture.

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FOREST INFLUENCES.

I.—INTRODUCTION AND SUMMARY OF CONCLUSIONS.

By B. E. FERNOW.

INTRODUCTION.

One of the arguments upon which a change of policy in regard to our forests, and especially on the part of the National Government, is demanded, refers to the influence which it is claimed forest areas exert upon climate and waterflow. It is argued that the wholesale removal and devastation of forests affects climate and waterflow unfavorably.

Popular writers on forestry, friends of forestry reform, and the public mind have readily taken hold of this proposition, enlarged upon it, and generalized without sufficient and relevant premises, and before it was possible for science and systematic observations to furnish grounds or sound deductions; hence we have had only presumptions supported by superficial reasoning and occasional experiences. Even scientific writers have discussed the question without proper basis, and have sought to reason out the existence or absence of such an influence upon general premises and such evidence as the history of the world seemed to furnish, or else upon observations which were either of too short duration to allow elimination of other disturbing factors or else were otherwise unreliable.

From the complication of causes which produce climatic conditions it has always been difficult to prove, when changes of these conditions in a given region were observed, that they are permanent and not due merely to the general periodic variations which have been noted in all climates of the earth, or that they are due to a change of forest conditions and to no other causes; hence some climatologists have thought proper to deny such influences entirely. On the other hand, there are as trustworthy and careful observers who maintain the existence of such influences; but only of late has the question been removed from the battle-field of opinions, scientific and unscientific, to the field of experiment and scientific research, and from the field of mere speculation to that of exact deduction. But the crop of incontrovertible facts is still

scanty, and further cultivation will be necessary to gather a fuller harvest and then to set clear the many complicated questions connected with this inquiry.

Meanwhile a thorough beginning with a view to settle the question by scientific methods and careful systematic measurements and observations has been made in Europe, where the existence of well-established forest administrations, manned with trained observers, has rendered practicable the institution of such work on an extensive scale—the only one which can yield adequate results. Notably the observations made at the duplicate stations in Prussia, and recorded for fourteen successive years, furnish reliable material for the discussion at least of the relation of forest cover to meteorological phenomena, and from these in time the nature and extent of any influence upon the climate, if such exists, may be determined.

Prof. M. W. Harrington, now Chief of the Weather Bureau, has, in the following pages, compiled these and other observations, and in an ingenious manner has compressed them into graphic illustrations, which readily convey the results to the reader. While an attempt has been made to discuss the problems and records in popular form, the student of forest meteorological problems will find not less useful the clear and unbiased statements of what these problems involve and what the records do and do not show.

It may be proper to call attention to and accentuate the fact that the question of practical importance is not so much as to the effects upon the general climate, but as to the local modification of climatic conditions which a forest area may produce.

It can not be too strongly impressed upon those who disclaim any influence of forest cover on climate, because the cosmic causes by which this is produced are immeasurably greater, that there are two classes of climate always to be considered separately, namely, the general climate and the local climate. The latter is of most importance to us, and alone can be modified by small causes. We modify it by building a house around us, thus altering the temperature and moisture conditions of the atmosphere so inclosed; but the question is, whether we can alter these conditions on a larger scale by such means as alternating forest areas and fields or by large bodies of forest. We are not so much concerned as to whether the total rainfall over the continent is increased, but whether the distribution of precipitation in time and quantity over and near a forest area is influenced by its existence; whether we or our crops feel its absence or presence in our immediate neighborhood; whether the protection it seems to afford and the changes it seems to produce in the meteorological phenomena are or are not real and of sufficient magnitude to influence our forest policy.

We would here call special attention to the memoir of Prof. Cleveland Abbe, contained in this bulletin, from which the difficulty of obtaining accurate records of rainfall with the gauges in general use is

apparent. When we find our means of measurement so deficient we must be careful how far we base conclusions on their records.

In this connection the very suggestive paper by Mr. George E. Curtiss, contained in this bulletin, should receive attention. His classification of rains into convective, orographic, and cyclonic will certainly assist in developing true conceptions as to cause and effect and possible relation of surface conditions to rainfall.

While, then, conclusive deductions may perhaps not be as yet admissible, we can not refrain from pointing out the results obtained in the forest station at Lintzel (recorded on page 113), which seem to show that forest-planting did, under the conditions there prevailing, produce a considerable change in meteorological conditions.

We can understand readily that if any influence exists it must be due, in the first place, to the mechanical obstruction which the forest cover presents to the passage of air currents and to the action of the sun's rays upon the soil—it must result from a difference in insolation and consequent differences in temperature and evaporation over forest and field. It is also readily understood that the influence can become appreciable only when large enough areas exhibiting such differences are opposed to each other, capable of producing local currents of air which may intercommunicate the characteristics of the one area to the other. The size and character of the forest growth, its density, height, situation, and composition, are, therefore, much more important in determining its influence than has been hitherto supposed. It is not trees, but masses of foliage, which may be effective. A large sheet covering an extended area from the influence of the sun would produce almost the same differences in meteorological conditions that a forest cover is expected to produce.

While, then, we may admit *a priori* that extent or area and condition of the forest cover are important, we have as yet no data from which to calculate any proper size or proportion, and the attempts to fix a certain percentage of forest cover needed for favorable climatic conditions of a country are devoid of all rational basis.

Leaving the question of forest influences upon climate as still awaiting final solution, we may speak with much more confidence of the effect which forest cover exerts upon the disposal of water supplies. This effect can be much more readily studied and shows itself much more conspicuously. It is perhaps also much more important to human economy, for it is becoming more and more apparent that our agricultural production is dependent not so much upon the amount of rainfall as upon the proper disposal of the waters that fall.

Recognizing this truth, the American Association for the Advancement of Science, in 1891, sent the following resolution to the Secretary of Agriculture:

The American Association for the Advancement of Science respectfully submits for the consideration of the Secretary of Agriculture that the future of successful and more productive agriculture depends very largely upon a rational water manage-

ment, meaning thereby not only the use of water for irrigation in the arid and subarid regions, but the rational distribution and use in the humid regions of available water supplies by means of horizontal ditches and irrigation systems, combined with proper mechanical preparation of the soil, and with drainage systems, with the object of fully utilizing the water for plant production and providing for the safe and harmless removal of the surplus.

The present policy of forest production and of allowing our waters to run to waste not only entails the loss of their beneficial influence upon plant production, but permits them to injure crops, to wash the fertile mold from the soil, and even to erase and carry away the soil itself.

It is upon these considerations that the association respectfully suggests to the honorable Secretary the desirability of utilizing the Weather Bureau, the various agricultural experiment stations, and other forces, in forming a systematic service of water statistics, and in making a careful survey of the condition of water supplies, which may serve as a basis for the application of rational principles of water management.

How poorly we understand the use of these supplies is evidenced yearly by destructive freshets and floods, with the accompanying washing of soil, followed by droughts, low water, and deterioration of agricultural lands.

It may be thought heterodox, but it is nevertheless true that the manner in which most of the water of the atmosphere becomes available for human use (namely, in the form of rain) is by no means the most satisfactory, not only on account of its irregularity in time and quantity, but also on account of its detrimental mechanical action in falling; for in its fall it compacts the ground, impeding percolation. A large amount of what would be carried off by underground drainage is thus changed into surface-drainage waters. At the same time by this compacting of the soil capillary action is increased and evaporation thereby accelerated. These surface waters also loosen rocks and soil, carrying these in their descent into the river courses and valleys, thus increasing dangers of high floods and destroying favorable cultural conditions.

Here it is that water management and, in connection with it or as a part of it, forest management should be studied; for *without forest management no rational water management is possible.* The forest floor reduces or prevents the injurious mechanical action of the rain and acts as a regulator of water flow. Hitherto water management in rainy districts has mainly concerned itself with getting rid of the water as fast as possible, instead of making it do service during its temporary availability by means of proper soil management, horizontal ditches and reservoirs—drainage and irrigation systems combined. It seems to have been entirely overlooked that irrigation, which has been considered only for arid and subarid regions, is to be applied for plant production in well-watered regions with equal benefit and profit, if combined with proper drainage systems and forest management. A discussion of the manner in which the forest influences the disposal of water supplies has been made a special part of this publication.

It will be observed in this bulletin that the historical method of discussing the subject of forest influences, which consists in adducing general observations throughout the world, has given place to the scientific method, which relies upon specific observations and experiments and upon the application of well-established physical laws to the explanation of the facts observed.

SUMMARY OF CONCLUSIONS.

For those who wish to know only what the present state of the question of forest influences is, we have summarized what conclusions may be drawn from the facts presented in this bulletin, referring them to the body of the report for the basis of these conclusions and the discussion *in extenso*. This arrangement, we are aware, is not customary and logical, but since the object of this bulletin, to some extent, is to familiarize not only the student but the general public with the subject, it seemed expedient to meet the convenience of the general reader in this manner. For easy reference the pages of this bulletin containing the data upon which each conclusion is reached are given in parentheses at the end of each paragraph.

GENERAL CONSIDERATIONS.

(1) We must keep separate two main questions, namely, What is the difference of conditions within and without the forest? and How far is the difference of conditions within the forest communicated to the outside, *i. e.*, how far does the forest influence the conditions outside? (Pp. 23–40.)

(2) The general climatic conditions in which the forest is situated as well as its situation with reference to elevation and exposure, furthermore its composition, whether evergreen or deciduous, its density, its height and extent, the character of the forest floor, and other features which determine its quality, must all combine in producing variety, at least quantitatively, both as to difference of conditions within and without the forest, and as to possible exchange of the same, and hence the question of forest influences can be properly discussed only with reference to these other conditions. We must refrain from generalizing too readily from one set of conditions to another set of conditions. (Pp. 40–121.)

(3) In the matter of forest influence upon waterflow, besides the above mentioned, other conditions, the topography and geology or stratification of soil, must also be taken into account and generalizations without regard to these must be avoided. (Pp. 123–157.)

(4) No influence upon the general climate which depends upon cosmic causes can in reason be expected from a forest cover. Only local modifications of climatic conditions may be anticipated; but these modifications if they exist are of gre .t practical value, for upon them

rest success or failure in agricultural pursuits and comfort or discomfort of life within the given cosmic climate. The same condition must be insisted upon with reference to forest influences upon waterflow, which can exist only as local modifications of water conditions, which are due in the first place to climatic, geologic, and topographic conditions. (Pp. 157–170.)

DIFFERENCE OF METEOROLOGICAL CONDITIONS WITHIN AND WITHOUT THE FOREST.

(1) *Soil temperatures.*—The general influence of the forest on soil temperatures is a cooling one, due to the shade and to the longer retention of moisture in the forest floor as well as in the air, which must be evaporated before the ground can be warmed. As a consequence the extremes of high and low temperature within the forest-soil occur much later than in the open, and both extremes are reduced, but the extreme summer temperatures much more than the winter temperatures.

The difference between evergreen and deciduous forests, which almost vanishes in the winter time, is in favor of the deciduous as a cooling element in summer and autumn, while during spring the soil is cooler under evergreens. The effect increases naturally with the age and height of the trees.

(2) *Air temperatures under the crowns.*—The annual range of air temperature is smaller in the forest than in the open; the effect upon the minimum temperature (*i. e.*, the effect in winter) is less than on the maximum temperature (*i. e.*, the effect in summer). The combined effect is a cooling one. The range of temperature is more affected than the average absolute temperature, or, in other words, the moderating influence is greater than the cooling effect.

The monthly minima for middle latitudes are uniformly reduced during the year, and the monthly maxima are much more reduced during the summer than during the winter. On the average the forest is cooler than the open country in summer, but about the same in winter, with a slight warming effect in spring.

The difference between the mean monthly air temperatures in the woods and in the open varies with the kind of forest much more than is the case for soil temperatures. The evergreen forest shows a symmetrical increase and decrease throughout the year. The deciduous forest shows a variable influence which diminishes from the midwinter to springtime, but increases rapidly as the leaves appear and grow, becoming a maximum in June and July and then diminishing rapidly until November. The annual average effect is about the same both for evergreens and deciduous forests.

Forests situated at a considerable elevation above the sea have sensibly the same influence on the reduction of the mean temperature as do forests that are at a low level.

Young forests affect the air temperature very differently from mature forests; in the former the minimum temperatures are always reduced, but the maxima are exaggerated. The observations on which this conclusion is based ought, perhaps, to be considered as pertaining rather to the case of temperatures in the tree-tops.

(3) *Air temperatures within the crowns.*—The mean temperature of the air in the tree-tops, after correcting for elevation above ground, is rather higher than over open fields. The effect of tree-tops does not appreciably depend upon the height of the station above ground. The effect upon the minima is generally greater than on the maxima, the total effect being a warming one. A tree-top station is in general intermediate, as to temperature, between a station near the ground in the forest and one in the open field.

Evergreen forests show less difference between the temperature in the crown and below, and altogether more uniformity in temperature changes throughout the year, than deciduous growth.

The vertical gradient for temperature within the forest on the average of all stations and all kinds of forest trees is large, varying from 0.61° F. per 100 feet in April to 2.50° F. in July.

A reversal of the vertical gradient, namely a higher temperature above than below, occurs in the woods, especially in the summer time. It also occurs in the open air regularly at night, and may be three or four times as large as that just mentioned. In general the action of the forest tends to produce a vertical distribution of temperature like that over snow or level fields on clear nights.

(4) *Air temperature above the crowns.*—The temperature, at considerable heights above the forest, appears to be slightly affected by the forest and more so with evergreens than with deciduous growth. The vertical gradients of temperature within 30 feet above the tops of the trees are all reversed throughout the leafy season; the gradients are also greater above the tree crown than below, at least during the clear sky and calm air. The wind affects the temperature under and within the crowns, but makes little difference above them. The surface of the forest crown appears meteorologically much like the surface of the meadow or cornfield. It is as if the soil surface has been raised to the height of the trees.

(5) *Air temperature in general.*—From the preceding generalizations it appears that the forest affects the temperature just as any collection of inorganic obstacles to sunshine and wind; but as an organic being the forest may be also an independent source of heat. Careful observations of the temperature within the trunk of the tree and of the leaves of the tree show that the tree temperature is affected somewhat by the fact that the rising sap brings up the temperature of the roots while the return sap from the leaves brings their temperature down, and the tree temperature considered as the result of the complex adjustment is not appreciably affected by any heat that may be evolved by the chemi-

cal processes on which its growth depends. It is not yet clear as to whether the chemical changes that take place at the surface of the leaves should give out any heat; it is more likely that heat is absorbed, namely rendered latent, especially in the formation of the seed; the process of germination usually evolves this latent heat; the immense quantity of water transpired and evaporated by the forests tends to keep the leaves at the same temperature as that of the surface of water or moist soil.

(6) *Humidity of air.*—The annual evaporation within the forests is about one-half of that in the open field; not only is the evaporation within a forest greatest in May and June, but the difference between this and the evaporation in the open field is also then a maximum, which is the saving due to the presence of the woods. The average annual evaporation within the woods is about 44 per cent of that in the field. Fully half of the field evaporation is saved by the presence of the forest.

The quantity of moisture thrown into the air by transpiration from the leaves in the forest is sometimes three times that from a horizontal water surface of the same extent, and at other times it is less than that of the water. The transpiration from leaves in full sunshine is decidedly greater than from leaves in the diffused daylight or darkness. The absolute amount of annual transpiration as observed in forests of mature oaks and beeches in central Europe is about one-quarter of the total annual precipitation.

The percentage of rainfall, evaporated at the surface of the ground, is about 40 per cent for the whole year in the open field and about 12 per cent for the forest, and is greater under deciduous than under evergreen forests.

The evaporation from a saturated bare soil in the forest is about the same as that from a water surface in the forest, other conditions being the same.

The presence of forest litter like that lying naturally in undisturbed forests hinders the evaporation from the soil to a remarkable extent, since it saves seven-eighths of what would otherwise be lost.

The total quantity of moisture returned into the atmosphere from a forest by transpiration and evaporation from the trees and the soil is about 75 per cent of the precipitation. For other forms of vegetation it is about the same or sometimes larger, varying between 70 per cent and 90 per cent; in this respect the forest is surpassed by the cereal and grasses, while, on the other hand, the evaporation from a bare soil is scarcely 30 per cent of the precipitation.

The absolute humidity within a forest exceeds that of the glades and the plains by a small quantity. The relative humidity in the forest is also larger than in the glades or plains by 2 per cent to 4 per cent. Forests of evergreens have from two to four times the influence in increasing relative humidity than do forests of deciduous trees.

The gauges in European forest stations catch from 75 to 85 per cent

when placed under the trees, the balance representing that which passes through the foliage and drips to the ground or runs down along the trunks of trees, or else is intercepted and evaporated. The percentage withheld by the trees and which either evaporates from their surface or trickles along the trunk to the ground is somewhat greater in the leafy season, though the difference is not great. Deciduous and evergreen trees show but slight differences in this respect. More rain is usually caught by gauges at a given height above the forest crown than at the same height in open fields, but it still remains doubtful whether the rainfall itself is really larger over the forests, since the recorded catch of the rain-gauge still requires a correction for the influence of the force of the wind at the gauge.

In such cases where over a large area deforestation and reforestation have seemingly gone hand in hand with decrease and increase of rainfall, the possible secular change in rainfall must also be considered. Yet the experience of increased rainfall over the station at Lintzel (p. 113), with increase of forest area, points strongly toward a possible interdependence under given conditions.

By condensing dew, hoar frost, and ice on their branches, trees add thereby a little to the precipitation which reaches the ground, and by preventing the rapid melting of snow more water remains available under forest cover.

The question as to the march of destructive hailstorms with reference to forest areas, which seems settled for some regions in France, remains in doubt for other, especially mountain, regions.

From these statements we would expect as a consequence of deforestation an effect on the climate of the deforested area in three directions, namely: (*a*) extremes of temperature of air as well as soil are aggravated; (*b*) the average humidity of the air is lessened, and possibly (*c*) the distribution of precipitation throughout the year, if not its quantity, is changed.

INFLUENCE OF FORESTS UPON THE CLIMATE OF THE SURROUNDING COUNTRY.

(1) An influence of the forest upon the climate of its surroundings can only take place by means of diffusion of the vapor which is transpired and evaporated by the crowns and by means of air currents passing through and above the forests being modified in temperature and moisture conditions; the mechanical effect upon such air currents by which they are retarded in their progress may also be effective in changing their climatic value.

(2) Local air currents are set up by the difference in temperature of the air within and without the forest, analogously to those of a lake or pond, cooler currents coming from the forest during the day in the lower strata and warmer currents during the night in the upper strata.

The latter currents, being warmer and moister, can be of influence on the temperature and moisture conditions of a neighboring field by moderating temperature extremes and increasing the humidity of the air.

This local circulation is the one most important difference between forest and other vegetation. How far away from the forest this circulation becomes sensible is not ascertained. In winter time, when the temperature differences become small, no such circulation is noticeable.

(3) The general air currents in their lower portions are cut off entirely by the forest, which acts as a windbreak. This influence can of course be experienced only on the leeward side. How far this protection reaches it is difficult to estimate, but it certainly reaches farther than that of a mere windbreak, since by the friction of the air moving over the crowns a retardation must be experienced that would be noticeable for a considerable distance beyond the mere windbreak effect. Deforestation on a large scale would permit uninterrupted sweep of the winds, a change more detrimental where the configuration of the ground does not fulfil a similar function—in large plains more than in hilly and mountainous regions, and at the seashore more than in the interior.

The upper air strata can be modified only by the conditions existing near and above the crowns. At the same time they must carry away the cooler and moister air there and create an upward movement of the forest air, and thereby in part the conditions of this become also active in modifying air currents. The greater humidity immediately above the crowns is imparted to the air currents, if warm and dry, and becomes visible at night in the form of mists resting above and near forest areas. These strata protect the open at least against insolation and loss of water by evaporation, and have also a greater tendency to condensation as dew or light rain, if conditions for such condensation exist. This influence can be felt only to the leeward in summer time and with dry warm winds, while the cooling winter effect upon comparatively warmer moist winds is not noticeable. Theoretical considerations lead to the conclusion that in mountain regions only the forest on the leeward slope can possibly add moisture to a wind coming over the mountain, but this does not necessarily increase the precipitation on the field beyond. Altogether the theoretical considerations are as yet neither proved nor disproved by actual observations, and as to rainfall the question of influence on the neighborhood is still less settled than that of precipitation upon forest areas themselves. Wherever moisture-laden winds pass over extensive forest areas the cooler and moister condition of the atmosphere may at least not reduce the possibility of condensation, which a heated plain would do; but observations so far give no conclusive evidence that neighboring fields receive more rain than they otherwise would.

(4) With regard to comparative temperatures in forest stations and open stations that are situated not far apart from each other, it would

appear that the forest exerts a cooling influence, but that more detailed conclusions are hindered by the consideration that the ordinary meteorological station itself is somewhat affected by neighboring trees.

The study of the stations in Asiatic and European Russia seems to show that in the western part of the Old World the presence of large forests has a very sensible influence on the temperature. Similar studies for stations in the United States seem to show that our thin forests have a slight effect in December but a more decided one in June. It appears also that our wooded regions are warmer than the open plains, but there is no positive evidence that this difference of temperature is dependent upon the quantity or distribution of forests, or that changes in temperature have occurred from this cause.

(5) When a forest incloses a small area of land, forming a glade, its inclosed position brings about special phenomena of reflection of heat, local winds, and a large amount of shade. For such forests it is found that the mean range of temperature is larger in the woods than on the open plain; the glade climate is more rigorous than the climate of open plains; the glade is cooler and its diurnal range larger during the spring, summer, and autumn.

Favorable influences upon moisture conditions of the air are most noticeable in localities where much water is stored in underground with overlying strata which are apt to dry when our summer drought prevails. Here the forest growth is able to draw water from greater depths and by transpiration return it to the atmosphere, thereby reducing the dryness and possibly inducing precipitation. In most climates this action would be less effective or of no use. Hence in regions with oceanic climate with moist sea winds like England and the west coasts of Europe or of the northern United States, deforestation from a climatic point of view may make no appreciable difference, such as it would make in continental climates like the interior of our country, the Rocky Mountains, and southern California.

Whether large or small areas of forest and open fields alternating, or what percentage of forest is most favorable can not as yet be discussed, since we are not clearly informed even as to the manner and the amount of influence which forest cover exercises. In general we may expect that an alternation of large forested and unforested areas, in regions which on account of their geographic situation have a dry and rigorous climate, is more beneficial than large uninterrupted forest areas, which would fail to set up that local circulation which is brought about by differences in temperature and permits an exchange of the forest climate to the neighboring field.

INFLUENCE OF FORESTS UPON WATER AND SOIL CONDITIONS.

(1) In consequence of deforestation evaporation from the soil is augmented and accelerated, resulting in unfavorable conditions of soil humidity and affecting unfavorably the size and continuity of springs. The influence of forest cover upon the flow of springs is due to this reduced evaporation as well as to the fact that by the protecting forest cover the soil is kept granular and allows more water to penetrate and percolate than would otherwise. In this connection, however, it is the condition of the forest floor that is of greatest importance. Where the litter and humus mold is burned up, as in many if not most of our mountain forests, this favorable influence is largely destroyed although the trees are still standing.

(2) Snow is held longer in the forest and its melting is retarded, giving longer time for filtration into the ground, which also being frozen to lesser depth is more apt to be open for subterranean drainage. Altogether forest conditions favor in general larger subterranean and less surface drainage, yet the moss or litter of the forest floor retains a large part of the precipitation and prevents its filtration to the soil, and thus may diminish the supply to springs. This is especially possible with small precipitations. Of copious rains and large amounts of snow water, quantities, greater or less, penetrate the soil, and according to its nature into lower strata and to springs. This drainage is facilitated not only by the numerous channels furnished by dead and living roots, but also by the influence of the forest cover in preserving the loose and porous structure of the soil.

Although the quantity of water offered for drainage on naked soil is larger, and although a large quantity is utilized by the trees in the process of growth, yet the influence of the soil cover in retarding evaporation is liable to offset this loss as the soil cover is not itself dried out.

The forest, then, even if under unfavorable topographical and soil conditions (steep slopes and impermeable soils) it may not permit larger quantities of water to drain off underground and in springs, can yet influence their constancy and equable flow by preventing loss from evaporation.

(3) The surface drainage is retarded by the uneven forest floor more than by any other kind of soil cover. Small precipitations are apt to be prevented from running off superficially through absorption by the forest floor. In case of heavy rainfalls this mechanical retardation in connection with greater subterranean drainage may reduce the danger from freshets by preventing the rapid collection into runs. Yet in regions with steep declivities and impermeable soil such rains may be shed superficially and produce freshets in spite of the forest floor, and an effect upon water conditions can exist only from the following consideration.

(4) The well-kept forest floor, better than even the close sod of a meadow, prevents erosion and abrasion of the soil and the washing of soil and detritus into brooks and rivers.

This erosion is especially detrimental to agricultural interests as well as water flow in regions with this surface and impenetrable subsoils, and where rains are apt to be explosive in their occurrence, as in our western and southern country. The best soil of the farms is often washed into the rivers, and the water stages of the latter by the accumulations of this soil are influenced unfavorably.

(5) Water stages in rivers and streams which move outside the mountain valleys are dependent upon such a complication of climatic, topographic, geological, and geographical conditions at the headwaters of their affluents that they withdraw themselves from a direct correlation to surface conditions alone. Yet it stands to reason that the conditions at the headwaters of each affluent must ultimately be reflected in the flow of the main river. The temporary retention of large amounts of water and eventual change into subterranean drainage which the well-kept forest floor produces, the consequent lengthening in the time of flow, and especially the prevention of accumulation and carrying of soil and detritus which are deposited in the river and change its bed, would at least tend to alleviate the dangers from abnormal floods and reduce the number and height of regular floods.

SANITARY INFLUENCE OF FORESTS.

(1) The claimed influence of greater purity of the air due to greater oxygen and ozone production does not seem to be significant.

(2) The protection against sun and wind and consequent absence of extreme conditions may be considered favorable.

(3) The soil conditions of the forest are unfavorable to the production and existence of pathogenic microbes, especially those of the cholera and yellow fever, and the comparative absence of wind and dust, in which such microbes are carried into the air, may be considered as the principal claim for the hygienic significance of the forest.

We may summarize that the position of the forest as a climatic factor is still uncertain, at least as to its practical and quantitative importance, but that its relation to water and soil conditions is well established. As a climatic factor it would appear that the forest of the plain is of more importance than that of the mountains, where the more potent influence of elevation obscures and reduces in significance the influence of their cover; as a regulator of water conditions the forest of the mountains is the important factor; and since this influence makes itself felt far distant from the location of the forest, the claim for attention of Government activity and for statesmanlike policy with reference to this factor of national welfare may be considered as well founded. Every civilized government must in time own or control the

forest cover of the mountains in order to secure desirable water conditions.

In conclusion I may urge that systematic observations bearing on the subject of foreign influences should be instituted in this country by a Government agency, perhaps under the authority of the Weather Bureau and with the coöperation of the agricultural experiment stations. No other country is so well adapted for the study of this question as the United States, offering all the varying climatic conditions of a whole continent under one government, with changes in forest conditions constantly progressing.

II.—REVIEW OF FOREST METEOROLOGICAL OBSERVATIONS: A STUDY PRELIMINARY TO THE DISCUSSION OF THE RELATION OF FORESTS TO CLIMATE.

By M. W. HARRINGTON.

THE NATURE OF THE PROBLEM.

The covering of the earth's surface determines many of the minor features of climate, and especially those features which are of importance for agriculture. The insular climate, the coast climate, the desert and prairie climates, the differences between steady winters with continuous snow-covering and variable winters with little or no snow, all have peculiarities that are due to the character of the covering of the earth's surface at or near the station which has the climate in question.

A striking illustration of the effect of the surface-covering on climate and weather is seen in the case of a snow-covering. This has been studied recently by an eminent Russian meteorologist, Dr. Woeikoff, who finds the influence of the snow to be surprisingly far-reaching. It chills and equalizes the temperature; it promotes the passage of blizzards and other winter storms; it retards the spring; it feeds the water more slowly to the streams; it promotes the continuance of clear, dry weather with high barometric pressure; and it has many other effects which are of hardly less importance.

The forest is to be considered, in its effects on climate and weather, as a special form of surface-covering. Its effects are of the same order as those produced by a covering of sand, or sod, or water, but the forest effect has some peculiar features which are due to the fact that the covering is elevated to some extent above the soil. This imparts to the soil in some degree the climatic characteristics due to a topographical elevation, and also causes a series of wind-break effects which are not found with the other forms of surface-covering. On account of this distinctive feature, the problem of forest climatology separates into two problems, which must be considered each by itself. The one relates to the climate of the interior of the forest, the other to the effects of the forest on the climate of the open country around it. The two are quite different; the first is of relatively little importance except as it relates to the second. It is the second which is of interest

and importance so far as relates to the suitability of a climate for residence and agriculture.

The solution of these two problems is very much complicated by the variety of conditions of the forest itself. The forest, woods, or woodlands may vary in extent all the way from the Amazon forest, which covers a large part of South America, or the corresponding forests of tropical Africa, to the woodlot of the farm, the grove, or the park. In density of tree-growth they vary quite as widely. The openings in forests are especially subject to forest climatic action, as any one knows who has found himself in a tropical forest glade at the hottest hour of the day; and these openings vary in form and in size all the way from the forest gallery or swale through the oak openings and little prairies to the regions where the prairies prevail and the forest is reduced to islands of woods or to fringes along the streams. In height the trees range from upwards of 300 feet to the low coppice or brush of a few feet elevation; some forests are of fairly uniform height, like the northern forests of firs and spruces, while others are composed of plants of all heights from the herb to the forest giant. This is mostly the case with the tropical forests where the giants are scattered between high and low trees and open glades, so arranged that the sunbeams, notwithstanding the density of the vegetation, sift through to the soil itself. In undergrowth, in persistence of leaves, and in quantity of shade, there is also every possible variation.

The effect of a mixed forest of deciduous trees must differ from that of an evergreen forest with needle-shaped leaves, and this again from forests of such trees as flourish in Australia, New Holland, and elsewhere, whose leaves stand more vertically so that the shade bears little relation to the leafiness. Such trees are found in many parts of the world; our own Kentucky coffee tree, is of this sort, and the lack of shade under a tree of this kind in full leaf in July is always a surprise.

Again, the litter accumulating in the forest has an important influence on its action, and the effects of the forest must be also much modified by many factors which determine its condition but are not strictly a part of it, such as the soil on which it grows, the abundance or scarcity of water, the slope of the land, the altitude above sea level, the latitude, and the prevailing degree of cloudiness. Any of these peculiarities may sensibly modify not only the climate of the interior of the forest but also the influence which the forest may exert on the climate of adjacent territory.

The literature of forest meteorology is already a large one. Löffelholz-Colberg published in 1872 a catalogue of the publications on the significance and importance of the forest, and since the issue of that catalogue the literature of the subject has grown at a rapid rate. Nearly all the publications to which he refers bear on the meteorological aspects of the forest. The longer bibliographical references given by

him number 190, and there are briefer references to very many more. Löffelholz-Colberg's list begins with Fernando Columbus, the son of Christopher Columbus, who attributes the heavy rainfall on Jamaica to its wealth of forests, and the decrease of rain on the Azores and Canaries to the removal of their forests. In the sixteenth and seventeenth centuries the subject was already attracting the attention of the French Government, and in fact governmental interest in the subject goes back to the time of the immediate successors of Charlemagne. It is interesting to read over the abstracts of opinions which are recorded in Löffelholz-Colberg's small book. Every variety of opinion can be found there, from those which attribute to the forest about everything which is desirable in climate and even endow it with a powerful influence on morals, to those who believe it is entirely without influence; and from those who think that its influence does not extend beyond its own margin, to those who would attribute the deterioration of the climate of the Old World to the removal of the forests of the New. The reasons for this extraordinary variation in opinion are to be found in the method employed for solving the problems of forest meteorology. Leaving out of account the solutions which were purely sentimental or purely touristic, the conclusions were generally founded on what may be called the historical method. This consists in finding a country which has been once wooded, but from which the forests have been removed, or one which was once open, but later became wooded. The climate at the beginning and end of the time involved is then ascertained or assumed, and the changes in the climate are attributed to the change in the forest cover. The uncertainties of this method are so great as to make it generally useless. It is seldom possible to be sure of the early forest condition of the country in question. For this purpose reliance must generally be placed on incidental references by the earlier writers, and these are usually ambiguous and uncertain. Even where the change in forest conditions can be proved beyond the possibility of doubt, the character of the early climate can not be ascertained with a sufficient degree of accuracy. If the period in question preceded the introduction of meteorological instruments, then the character of the climate must be judged by the nature of the crops raised or from facts of a similar nature given by earlier writers. If observations were taken they were generally rude and by means of imperfect instruments: their errors would probably approach in magnitude the quantity of forest influence which is to be determined. Besides, the fixing of the data of climate with our modern exact instruments and better methods requires observations for a long series of years. The variations of the elements of climate (the temperature, humidity, rainfall, winds, and cloudiness) are great from day to day and from year to year, and it takes numerous observations, scattered through many years and taken on a uniform system, to give fixed values for the climate. The rainfall for two successive years on the same spot might

differ by several times as much as the difference which could be reasonably expected between that on prairie and on forest. In addition to this, there is no certainty, generally, that any change of climate which is satisfactorily proven is necessarily due to a change in the forest. Changes are constantly going on in the climate of all stations and entirely without obvious connection with surrounding forest conditions. In fact, their causes are beyond our present knowledge.

These are the secular changes, so called; they are probably periodic, and their periods may be tens, scores, or hundreds of years. It is hardly possible to find a long series of observations in which traces of these secular changes are not evident.

The historical method has really given but meagre results of a reliable character. On the other hand, the extravagant results to which it has sometimes led have cast discredit on the whole subject of the influence of forests on climate. It will not be used in what follows except in a single case, in which all the conditions which can reasonably be required seem to be fairly fulfilled.

There are also recognized results of forest action which are entirely distinct from the meteorological influences with which we are here concerned and which refer to soil and water conditions. Such is the influence of forests on the flow of surface water and the occurrence of floods, on the amount of ground-water and the preservation of springs, on the holding of movable soils or reclaiming of swampy ones. These are all of the highest importance, but they will not be considered here. The questions of temperature and of the changes of the air are the only ones belonging to forest meteorology proper.

SYSTEMATIC OBSERVATIONS IN FOREST METEOROLOGY.

There are several series of sporadic observations on forest meteorology made before the beginning of this century, as, for instance, Hunter's observations on the temperature of trees in 1775 and 1778, and Schaepff's observations on the same subject in New York in 1783. The first systematic observations seem to be those taken at Geneva from 1796 to 1800 by Pictet and Maurice. They referred to tree temperatures and were made on a horse-chestnut tree two feet in diameter.

The thermometer was placed in a hole in the north side of the trunk six inches deep, and the space around the stem was closed up with wax, so that the water and air from the outside would not influence the temperature shown by the instrument. The observations were made without interruption at sunrise, 2 o'clock p. m., and sunset. Comparative observations were made at the same time on a thermometer to the north, in the shade, and on four ground thermometers at depths of 3 inches, 1 foot 5 inches, 4 feet 3 inches, and 12 feet 8 inches. The observations were made with precautions similar to those now considered necessary, but not generally practiced at that time.

Kaemtz carried on a good many scattered but instructive forest and agricultural observations before the publication of his meteorology in 1831–'34. In 1839–'40, Bravais at Bossekop, and Thomas at Kaaford, both in Lapland, took a long series of winter tree temperatures. Bravais put the bulb of a mercurial thermometer in the heart of a living pine which was 6 inches in diameter. Thomas compared the temperatures of two large pines close together, one dead and the other living. The latter showed a slightly higher temperature than the former.

In the winter of 1857–'58, Bourgeau carried on a series of tree temperature observations at Fort Carlton, on the Saskatchewan River, latitude about 52°.

FRANCE.

The beginning, however, of systematic observations on the short-range forest meteorological problem of the relative condition of the air in and about forests and the incitement to the modern activity in this direction seem to have come from the observations of M. A. C. Becquerel and his son Edmund, which began at Chatillon-sur-Loing, about 70 miles south of Paris, on July 30, 1858. These observations, now relating to forest meteorology, now to some other branch of the science, now carried on at Chatillon or its vicinity, now at Paris in the Jardin des Plantes, and generally with the aid of the French Academy of Sciences, have been conducted by MM. Becquerel and his son from that time to a quite recent date, and are probably still continued.

The memoirs and briefer communications which have been made to the academy, based on these observations, form a large and highly instructive addition to knowledge in this science, and they have been abundantly drawn on by subsequent writers. It is in some respects an advantage, in others a disadvantage, that the Messrs. Becquerel have used a special form of instrument in their observations and have followed independent methods. The disadvantage lies in the fact that this makes the observations not strictly comparable with those taken at regular forest meteorological stations, and when the question is one of relatively small differences, as that of temperatures and rainfall within and without forests, this lack of comparability is a serious drawback. On the other hand, there is a great advantage in getting results by different methods and with different instruments, for it serves to get rid of errors that depend on the method. Conclusions drawn from two entirely different sorts of observations are worthy of more confidence than those drawn from two sets taken in the same way.

The observations of the Messrs. Becquerel were taken with electric thermometers. They depend on thermo-electric principles, and the elder Becquerel had published studies on them as early as 1826, and afterwards used them in determining the temperature of the different envelopes of flames. The instrument as used was composed of a closed circuit a part of which was of copper and a part of iron. The two are

soldered at the ends, and a galvanometer is introduced into the circuit. By the principles of thermo-electricity whenever the two soldered ends are at the same temperature, there is no current and the galvanometer is not affected. If one of the junctions is warmer than the other, then a current is produced in the one or other direction, and the needle of the galvanometer swings to the corresponding side. If now one junction is placed in the medium the heat of which is to be measured, and the other is left accessible and is warmed or cooled until the needle stands at zero, the temperature of the latter junction is the same as that of the former. One junction can be placed in a flame, or in an animal or plant, or at the top of a tree, or at a depth in the ground, and its temperature can be ascertained by manipulating the other.

This method requires many precautions, and can not be conveniently used for maximum and minimum temperatures, but in competent hands it is very serviceable and is capable of minute accuracy.

In the observations of the Messrs. Becquerel it was so arranged that a change of one degree of temperature would cause a deflection of ten degrees in the needle. The needle was brought to zero with the aid of a lens, and an accuracy of reading to a tenth of a degree centigrade in the galvanometer was abundantly assured. Every precaution was taken. For instance, a junction exposed to the rays of the sun was covered with a triple reflector which screened from the sun's rays, but permitted free ventilation. The results have every guarantee of accuracy and are worthy of unusual confidence.

M. Becquerel's first memoir relating to the forest meteorological problems was not published until 1864. Meantime other students of the subject were showing signs of activity. The French forest inspectors Contegril and Bellot took many observations in 1859 and 1860 on the disposal of rainfall in woods as compared with that in open fields, and similar observations were taken in southern France. Hofmann at Giessen, and Baur at Hohenheim had been taking forest observations for some time. In 1862 and 1863, Krutzsch, in Saxony, established nine forest stations; several were established in Bavaria, and Count Berchem-Hainhausen, in his private capacity as a large landowner, supported two in Bohemia. In 1866–68, in Posen, Rivoli, also a private landowner, made many simultaneous comparative observations in forests and fields, including temperature, humidity, and evaporation. His observations on individual features of forest action were confined to the season at which they were greatest. The fertile idea in modern forest meteorological observations consists in having comparative stations at which observations are taken simultaneously. These stations must be as nearly as possible alike, except that one is to be in the woods, the other outside. This happy idea, already employed by Becquerel and Rivoli, and doubtless by others, but not by all, was first put to systematic use under governmental auspices at stations near Nancy. The French forest administration undertook to set at rest the

questions of forest influence on climate, and to this end instructed the school of forestry at Nancy to undertake the necessary studies. In April, 1886, observations were commenced by Prof. Mathieu, of Nancy, with the view of determining the influence which a wooded or unwooded country has upon the moisture received from the air. Three stations were selected; they were described by Dr. Hough in his report for 1877,* page 262. The most interesting feature about them is the forest rain gauge at Cinq-Franchées. It was made to cover exactly the surface covered by the tree-top and was placed with the tree in the center, careful arrangements having been made to direct into the gauge all water which ran down the tree. In 1870 a fourth station was added, that of the agricultural station of the school. The altitude of this station is 712 feet, somewhat less than the others.

In February, 1874, forest observations were undertaken by MM. Fautrat and Sartiaux, and continued by the first. The stations were in the department of Oise, a few miles north of Paris. This is a rolling territory of no great elevations or irregularities, and the southern part, containing the better-known forest of Compiegne, is well wooded and somewhat swampy. One pair of stations was in the state forest of Halatte, about a cluster of oaks and hornbeams of twenty or thirty years. The forest itself is large, containing about twelve thousand acres. M. Fautrat had the happy idea of trying some observations above the forest. His stations were therefore duplicated, one being below at the height of 4½ feet (1.37 m.), the other above the trees about 20 feet (6.09 m.), and 46 feet (14.02 m.) above the ground. The forest station was reproduced 1,000 feet (304.8 m.) away in the open fields. Each station had thermometers, psychrometers, rain gauges, and evaporometer. Under the trees the number of rain gauges was increased to six, distributed in such a way as to give a good indication of the amount of rain passing through the foliage. The stations were on a soil of fine sand, cemented by clay, and were at an elevation of 354 feet (107.9 m.) (base) above the sea and 400 feet (121.9 m.) taken above the trees. About 5 miles (8.04674 kil.) away was a second pair of double stations; they were in and near the state forest of Ermenonville. The trees were twenty-five year pines, about 40 feet (12.19 m.) high. The stations at Halatte were duplicated here, including the elevation of the station above the trees. This brought the higher instruments to within a very short distance of the foliage—5 or 6 feet. The soil here was a coarse white sand, and the open-field station was on a sandy plain. The elevations above the sea were 302 (92.05 m.) and 341 (103.9 m.) feet. There were six ordinary gauges under the trees and an additional large one, over 5 feet (1.52 m.) in diameter, which surrounded the trunk of a large pine tree. The printed observations (in the *Comptes rendus*) are somewhat fragmentary and extend over about four years. There has

* Report on Forestry, vol. I, United States Department of Agriculture.

been printed a separate publication on this subject, but I have not seen it; its data are said by Dr. Lorenz-Liburnau to differ somewhat from those in the *Comptes rendus.*

GERMANY.

In 1868, with the aid of the Bavarian Government, Dr. Ebermayer began his well-known series of observations. The results for the first year were made the subject of an independent publication. They relate exclusively to the problem of the interior forest climate, and the conclusions reached by Dr. Ebermayer have been generally confirmed by later observations. Dr. Hough has devoted twenty pages of his report for 1877 (pp. 230–251) to an account of this service and an abstract of its results, so that they do not need to be detailed here. Dr. Ebermayer, then in the forestry school at Aschaffenburg, is now professor at Munich, and his publications on forest meteorological topics still continue. In the beginning of 1869 three pairs of parallel stations were established in Switzerland. They are also described by Dr. Hough in his report (p. 255) cited above.

In 1875 the German meteorological forestry service was established. The stations are here in pairs, one in the forest, the other outside, and the observations are made in succession at the two stations of each pair. The rule was adopted to have each of the stations at least 200 yards (182.8 meters) from the margin of the forest, but this was not found to be always practicable, and the distance in one place sinks to less than ninety yards (82.29 meters). The stations were selected to represent every variety of position possible as to distance from the coast, topography, and kind of trees, and each station of the pair was put under very similar conditions of soil and elevation. Seventeen such stations have been established; ten in Prussia, three on the Imperial lands, and one each in Würtemberg, in Brunswick, in Thuringia, and in Hanover. The observations at Würtemberg station continued only from the beginning of 1880 to the end of 1885. The other stations are still active; they are conducted on a uniform plan and are under the direction of Dr. Müttrich, of the academy of Eberswalde. The instruments are made by Fuess; they are carefully compared when put up and are regularly inspected once in five years. Instruments are kept in reserve at each station so that the defective ones can be at once replaced without breaking the continuity of the observations.

The Hanover station is Lintzel, and this is exceptional in that it is among the young plantations of trees now formed on the great Luneberger heath. Field and forest stations both exist, but tree-top observations are not made. The principal features of the stations are shown in the accompanying table, in which they are arranged in order from northeast to southwest. By the elevation is meant that indicated by the barometer, which is so nearly the same for each station of the pair that it may be taken from either. The readings are exact, except for

the third, fifth, sixth, seventh, eleventh, twelfth, and fourteenth stations, where they are approximate.

German stations for forest meteorology.

Station.	Latitude.	Longitude east of Ferro.	Elevation.	Kind of trees and age at founding of station.	Distance to margin of forest.		Beginning of observations.
					Forest station.	Field station.	
	° ′	° ′	*Feet.*		*Feet.*	*Feet.*	
Fritzen	54 50	38 13	128	45-year spruce	262	459	1873, x, i.
Kurwien	53 34	39 9	423	80–140-year pines	679	433	1873, xii, i.
Carlsberg	50 28	34 0	2, 484	45-year spruce	591	869	1874, xi, i.
Eberswalde	52 50	31 29	79	45-year pines	410	591	1875, xii, i.
Schmiedefeld	50 36	28 28	2, 349	60–70-year spruce	984	492	1881, x, i.
Friedrichsrode	51 52	28 14	1, 296	65–85-year beeches	367	1, 138	1874, x, i.
Sonnenberg	51 45	28 10	2, 549	45-year spruce	328	650	1877, vi, i.
Marienthal	52 16	28 38	420	60-year beeches	984	656	1878, v, i.
Lintzel	52 59	27 55	325				1881, iii, i.
Hadersleben	55 16	27 9	125	70–80-year beeches	410	394	1875, x, i.
Schoo	53 36	25 14	10	20-year pines	656	1, 640	1876, x, i.
Lahnhof	50 53	25 54	1, 998	70-year beeches	2, 461	640	1877, vi, i.
Hollerath	50 27	24 3	2, 024	45-year spruces	361	328	1874, x, i.
St. Johann	48 29	26 59	2, 493	50-year spruces	1, 640	656	
Hagenau	48 50	25 28	499	55–65-year pines	4, 167	2, 192	1875, v, i.
Neumath	48 59	24 57	1, 158	45-year beeches	820	820	1875, v, i.
Melkerei	48 25	24 57	3, 064	60–80-year beeches	3, 937	5, 249	1875, v, i.

The field station is generally on cultivated soil, in a few cases on meadows or marshy land.

A monthly and an annual report are published from these stations and the results have been made the subject of several special studies—notably the temperature observations have been discussed quite recently (1890) by Dr. Müttrich.

The observations are taken on the same plan as those in Bavaria, but observations of the tree temperatures and the measures of ground water are omitted.

SWEDEN.

In 1876 the Swedish observations were begun under the direction of the meteorological central office, and chiefly at the expense of the State. The stations are here selected in a different manner from those in the other services. There are few that are under trees; there are many more in small glades or openings in the forest, and the comparative field stations are usually quite distant and in a freely open country. This offers some advantages, for it permits the discussion of glade climate or the climate in the vicinity of forests, as distinguished from that under trees or that in open regions away from trees. A disadvantage is found in the fact that the results are not strictly comparable with the results of observations taken elsewhere. The observations have, for several years, been under the direction of Dr. H. E. Hamberg, who has published a discussion of the results in temperature and humidity, the first in 1885, the second in 1889. The publications made up to this time relate to temperature and humidity only.

Swedish stations for forest meteorology.

Station.	Character.	Latitude.	Longitude, east.	Altitude.	Situation.	Soil.	Distance to woods.	Kind of trees.
		° ′	° ′	*Feet.*			*Feet.*	
Tierp	Open	60 17	17 28	121	In village	Clay and sand	9,000	
Tobo	Glade	60 15	17 40	121	Marshy forest land	Clay	100	40-year pines and firs.
Dalboda	Forest	60 7	17 33	164	Marshy, near small lake	Sandy		80-year pines and firs.
Do	Glade	60 7	17 33	164	do	do	600	
Akerlänna	do	60 1	17 23	164	Marshy forest land	do	160	40-year pines and firs.
Bälinge	Open	59 57	17 32	92	Great plain of Upsala	Clay	4,000	
Upsala	do	59 52	17 38	79	Hill; small groves about	do	5,000	
Rekasta	do	59 41	17 4	69	Cultivated	do	1,600	
Alderstugan	Forest	59 41	16 17	200	Marshy forest land	Gravelly		60-year firs.
Do	Glade	59 41	16 17	200	do	Loam	360	60-year pines and birches.
Lillhärad	Open	59 39	16 23	98	Large plain	Hard clay	4,000	
Äugsvallen	Glade	59 38	17 12	69	In large forest	Loam	300	30–60-year pines and firs.
Signalsburg	do	59 38	17 19	66	Wooded, rough region	Gravel	200	30–50-year pines and firs.
Dingtuna	Open	59 34	16 24	39	Cultivated	Clay	300	
Sparhult	Forest	58 35	13 40	459	Wooded region	Sandy		70-year firs.
Do	Glade	58 35	13 40	459	do	do	230	30-year firs.
Osterplana	Open	58 35	13 26	574	Treeless terrace			
Helde	do	58 34	13 30	230	Cultivated		2,300	
Danielslund	Forest	56 15	12 52	33				
Skorpinge	do	56 14	12 51	33				

The stations mentioned so far were generally parallel stations, that is double, one set of instruments being in the woods, the other outside.

AUSTRIA.

The radial stations proposed by Dr. Lorenz-Liburnau were established in Austria in 1884 and following years. The outside stations in each radial system were to be in various directions and at varying distances from the stations in the forest.

Dr. Liburnau found great difficulty in arranging them, since some of the stations should be at considerable distances, and all of the same group should be at the same sea level. Naturally the arrangement would also require a separate and distinct forest of no great extent. These conditions were hard to fill and but few suitable places were found in the whole Austrian Empire. Up to the present time only three such groups of stations have been established:

(1) In northeastern Austria, the group about Karlslust on an extended plateau, between Retz and Znaim, with an average elevation of 1,300 feet (396 m.).

(2) In eastern Galicia, near the Russian boundary, on an extensive plateau, between Konstancya and Skala, with an average elevation of 886 feet (270 m.).

(3) On the northern base of the Carpathians, in the undulating region near Rachin, at an elevation of 1,300 (396 m.) to 1,600 feet (487.6 m.).

Observations of temperature and humidity were taken under the trees, also in the tree crowns and at various elevations above the trees. Corresponding observations at the same heights were made over open land.

The results of the observations during the years 1885 to 1887 so far published have not been before the writer.* From a review, however, it is learned that the director, Dr. Liburnau, a most competent authority, draws the following conclusions:

(*a*) The normal decrease of temperature with the elevation, observed in the open country, is modified in the forest, during the day, by the warming of the crown cover, especially of the upper portions. In the forest the crown cover has the same relation to the temperature as have the soil and the smaller vegetation in the open country. Thus the normal decrease of temperature with the elevation remains uniform in the open country, but is more modified in the forest under the influence of the warmed crown-cover than in the open country under the influence of the soil.

(*b*) During the night the crown cover has also the same relationship to the soil and vegetation of the open country, except that temperature reductions have different values.

(*c*) As the temperature in the forest is higher in the upper regions of the crown cover than in the lower and among the trunks and on the ground, especially during the day, it follows that the shade contributes more to its reduction of temperature

* Investigations into the humidity and condition of temperature of the forest and of the open country, and the results of the forest influence upon the climate in its proximity.

than transpiration; altogether, the cooling effect of transpiration up to this time seems to have been overestimated.

(*d*) The warming effect of the upper crown cover upon the temperature during the day in a beech growth extends only about 2 m. (6½ feet) above the crowns, and indeed is most pronounced in the warmest months.

(*e*) The absolute values of the temperature differences effected by the forest are not very important, but depend to a great extent upon the species of the trees on the one hand and the kind of soil cover of the open country on the other.

(*f*) It is remarkable that in the forest the relative humidity increases and decreases with the absolute humidity, whereas it is known that in general, and also at the station in the open country, these two climatic elements are inverse. This is accounted for by the fact that the forest is a source of atmospheric aqueous vapor as well as of cooling.

(*g*) The results of the investigations at Ried show that the aqueous vapors from the forest often affect the air to a great height. With this increase in the humidity of the atmosphere the chances of precipitation are increased.

From these observations Dr. Liburnau draws the following conclusions regarding the influence of forests upon the general climate of the region in its vicinity:

(*h*) Since the temperature in the forest, to above the crown-cover, is in most cases lower than it is below in the open country, it follows that modifying currents can arise from the forest at any time of the day, especially in a generally still atmosphere. In summer, during the night and toward morning, differences of temperature can produce a current of cool air from the forest and from the air strata immediately above the forest; in the warmer part of the day, however, such currents can be looked for only from below and in the crown cover.

(*i*) In the summer half of the year, winds coming from a distance and crossing a forest can be cooled below their original temperature by the influence of the forest considerably in the night and toward morning, but less during the day.

(*j*) The conclusions which Dr. Liburnau arrives at concerning atmospheric humidity are based for the most part on the results of the observations at Ried. It was established that winds from the forest (at least from a beech forest) convey a greater water supply into the neighboring open country. It depends, however, upon the original humidity of winds crossing a forest and upon the distribution of temperature whether or not their humidity will be increased and they will subsequently increase the humidity of the adjacent open country.

Hence Dr. Liburnau concludes that the humidity of warm and dry winds will be increased by the presence of a forest, but that such winds as are already quite thoroughly saturated can receive no essential addition of aqueous vapor, but only an increase in relative humidity. It was also observed at Ried that winds coming from the forest to the station in the open country have a higher humidity, both absolute and relative.

(*k*) Finally, Dr. Liburnau remarks with reference to the distant influence (of the forest) that this absolute humidity, as increased by the effect of the forest,* remains in the atmosphere as long as it is not lost by condensation, and that, on the other hand, the increased relative humidity decreases as soon as the forest air reaches the warmer open country.

* Within the last two months a further contribution from these stations has been published, discussing more in detail the influence of forest areas on the climatic condition of the neighborhood, which publication, unfortunately, could not be obtained in time for a review in this report. B. E. F.

OBJECTS AND METHODS.

In 1868, before the publication of Ebermayer's results or those of any other systematic series of co-operative observations in forest meteorology, the Congress of German Foresters and Farmers at Vienna, struck with the paucity of results from the much talked-of forest meteorological observations, put the subject in the hands of a special committee composed of the most eminent German students and authorities on the subject. The committee met at Regensburg in November. Its attention was chiefly directed to other aspects of the forestry question, but it proposed a sort of programme or series of problems as the proper object of forest meteorological observations. These are:

(1) Determination of the temperature under woods and outside.

(2) Investigation of the temperature of trees as compared with that of the soil and air.

(3) Investigation of the soil of forests, determination of its temperature at different depths, situations, exposure, and under different kinds of trees.

(4) Influence of the covering of the soil on damage by frost.

(5) Determination of rainfall under woods and outside.

(6) Influence of the covering on the humidity of the soil and on the evaporation from it.

(7) Determination of the amount of evaporation in the forest and without.

(8) Determination of the ground water at different depths, under woods and outside, with various aspects and under various kinds of trees.

(9) Determination of the amount of carbonic acid and of the humidity of the forest during the season of vegetation, under a more or less compact cover of foliage, under different trees and in varied situations.

This is an extensive programme, and is of interest as the first which had been formulated under such auspices. It will be noticed, however, that it does not include observations at any elevation, and especially observations above the woods. It does not seem to have occurred to the committee that meteorologically the forest is a sort of surface covering to be compared with that of sod or crops, sand or water, and that in other cases observations are taken as well above the surface covering as in it or below it. Observations above woods were, however, not included by the committee, and since this programme served to give object and aim to the new services of that day, as well as to those established later, these important observations have been almost entirely neglected.

The Prussian (afterward the German) forest meteorological service, established six years later, adhered, in most points, to the Regensburg programme. In its instructions to its observers it defines their task as that of furnishing observations on—

(1) The temperature of the air in forests compared with that in open fields.

(2) The temperature of the air at 5 feet elevation, compared with that in the tree crown.

(3) The hygrometric condition of the air within and without woods.

(4) The same at a height of 5 feet compared with that in the tree crown.

(5) Evaporation within and without the woods.

(6) The rain and snow reaching the ground within and without the woods.

(7) The temperatures of forest soil at the surface and at the depths of 6 inches, 1, 2, 3, and 4 feet, compared with the temperatures at corresponding depths in the open fields.

There were also the highly important conditions attached that the instruments and their disposition should be alike, and that the hours of observation and methods of reduction should be the same.

In the second international meteorological congress, held at Rome in April, 1879, it was resolved that—

In order to contribute to the progress of forest and agricultural meteorology, the congress recommends as a programme of study:

(1) The influence of the meteorological elements upon vegetation.

(2) The inverse influence of vegetation upon the meteorological elements.

(3) Agricultural warnings.

The congress, finding the subject too important to treat hastily, concluded to charge the international committee with the convening of a special international conference to take into consideration the development of agricultural and forest meteorology.

Such a conference convened at Vienna on the 6th of September, 1880. This was so representative a meeting and illustrated so well what the most able and most experienced men thought on this subject that the reports, remarks, and resolutions will be given at some length so far as they relate to the action of forests on climate. Dr. Lorenz-Liburnau, of the Austrian Department of Agriculture, and president of the conference, said that when the influence of vegetation on climate was referred to, solitary plants could not be meant. It was a question of masses of vegetation, such as meadows, moors, and forests. There was also a distinction to be made between the climatic action produced within the massed vegetation and that upon the vicinity. It is only for a forest that the question of the interior climatic action can arise, and on this question certain definite numerical results had been obtained for central Europe, in certain localities. These show that the inner temperatures are slightly lowered, the temperature extremes are moderated, the relative humidity is raised, and the evaporation diminished, while it remains doubtful whether the absolute humidity or the frequency or quantity of precipitation are changed.

As to the influence of vegetation on its vicinity, exact data do not exist, either for the forest or for other forms of vegetation in mass. Yet, on theoretical grounds, it can not be doubted that such an influence exists, within certain limits, and appropriate methods of observation must be able to show it. They should include observations on the temperature, precipitation, cloudiness, insolation, and wind. The conference adopted these views.

As to the method of observation, Dr. Liburnau pointed out that the existing arrangement of one station within and a station for comparison outside the region covered by the vegetation to be investigated

might be called the method of parallel stations. This is a commendable arrangement, and promises the speedier results, the more the climate at the station takes on a continental character. The distance of the stations of each pair from each other is an important point. In each pair the meteorological elements should be taken at the ordinary height and also in the tree crown. The temperature of trees and soil should be included. As to precipitation, it is of importance to get not only the amount which passes through the foliage, but also that which runs down the trunk. The penetration of precipitation into the soil, the evaporation from the surface in different kinds of forests and with different coverings of the soil are of importance because the state of humidity and temperature depends on them. Observations of ozone at different heights are contingently recommended. These observations should be exactly duplicated, so far as possible, at the field stations. The treetop observations should be duplicated by field observations at the same height. To get the influence of the forests on their vicinity, a different system of stations is desirable; this should be a system of radial stations as contradistinguished from the parallel system. This consists of one station in the forest and several outside, arranged in the directions of the four principal points of the compass. There should be at least two in each direction and at different distances from the forest, so that one set should include at least nine stations. All the observations carried on at the parallel stations should also be taken at the forest station of the radial system, but at the field stations the number of instruments may be reduced to a psychrometer, evaporometer (Piche's), and a rain gauge, and the observations at the height of the tree crown may be omitted.

The question of exposure of thermometers aroused much discussion and it was agreed that comparative observations should be undertaken. As to hours of observation, Dr. Müttrich favored morning and noon (2 p. m.), while M. Grandeau and Dr. Ebermayer favored morning and evening hours. Dr. Riegler thought the 2 p. m. observation was to be especially recommended because it was about the hour of maximum forest effect. The conference finally decided to recommend morning and evening hours, with the reading of maximum and minimum thermometers. Observations of insolation were discussed, but MM. Mascart and Tacchini assured the conference that no suitable actinometer exists. It was, therefore, decided that observations should at first be undertaken only on the time, duration, and relative intensity of sunshine; the latter on sensitive paper, at stations of the first order. The subject of an actinometer capable of giving insolation temperatures with exactness was recommended as a subject worthy of the especial attention of scientific institutions.

It was decided that soil temperatures should be taken at various depths up to 40 inches (1 mm). The humidity should be obtained by the means of August's psychrometer and a hair hygrometer, and tri-

daily observations should be taken. A long discussiou followed on Dr. Liburnau's recommendation of Piche's evaporometer. It was stated that the observations gave no means of comparison with actual natural processes, that the readings of the instruments were untrustworthy and the errors hard to correct, that it was desirable to follow more exactly the processes of nature, that it is not possible to find an instrument fulfilling all necessary conditions, and that on this account the Italian service had rejected all evaporometers. The conference finally decided that, while observations of evaporation were important, there is no form of measuring instrument which can be especially recommended. An instrument should be invented which would permit the measurement of evaporation from a free water surface and also from soils of different characters. Provisionally observations should be carried on with the weighing instruments and with Cantoni's modification of Piche's instrument.

Clouds should be observed; fog should be recorded when it covers the station and its density should be given on a predetermined scale. Herr Friesenhoff recommended a measurer of dew depending on the power of rock salt to appropriate atmospheric water. Drs. Neumayer and Ebermayer expressed the opinion that balance drosometers should be tried. They should have larger dimensions (2 feet square or more) which should be filled with different materials. The conference commended the subject of a good measurer of dew as a proper subject of study. The measurer of precipitation should be on the model recommended by the International Congress and Committee. The seepage of ground water is important, but the so-called lysimeter is not to be recommended. Wind observations should be taken, as at ordinary stations.

The system of parallel stations, already adopted in Bavaria, Switzerland, and at the other German stations, was especially commended. Radial stations were commended for the broader fields of observation, and it was recommended that a series of such stations should be established in eastern Germany and in Austria-Hungary, and the final recommendation was made that observations should be made at the forest station of each radial system, directly over the crown of the trees. Thus this happy method, the fundamental importance of which makes it strange that it was not employed from the first, reached at least the stage of recommendation for general use. The practical difficulty of its use is probably what has prevented its adoption. This could be easily overcome by the use of registering instruments which are made to run for fifteen days without attention, or by the use of the now excellent instruments for electric registry at a distance.

To the proposal of the first meteorological congress for replies as to what could best be done, Dr. Woeikoff made a suggestion which was not taken into consideration by the conference. He proposed India as the best field for such studies, especially with reference to rainfall.

For this purpose observations could best be taken in the central provinces and Berar, as they are hottest in April and May and the forests are extensive. India also permits a study of the effects of irrigation on forests.

The German service supplies each of its stations with psychrometer, maximum and minimum thermometers, six soil thermometers, barometer, evaporometer, and rain gauge. The soil thermometers for the surface and the depth of 6 inches are supported by small tripods. The four thermometers for greater depths are in wooden cases, open at the bottom and extending downward only so far that the bulb of the thermometer may remain in contact with the soil at the depth required. The cases are placed together and are open at the top to permit of ready access to the instruments. A cover over the open ends keeps out the water and exterior air currents. The thermometers are taken out for observation, read as quickly as possible, and replaced. The evaporometer is a square receptacle of zinc with a surface of about 2 square feet and a depth of about 5 inches. A measured amount of water is placed in it, and the loss, expressed in thickness of layer evaporated, is noted at the beginning of each month. This instrument is protected from precipitation by a wooden roof, but the air is permitted to have free access. The force and direction of the wind are estimated, the former on the 1 to 4 scale.

The rain gauge has an opening of about 2 square feet (18.58^{dm}) and is placed at a height of 5 feet (1.52^{m}), like the other instruments. The snow gauge has the same opening, but a larger body, to prevent the snow from being blown out.

The observers were intrusted with other observations, especially those relating to the leafing, flowering, and other stages of certain plants, and the list of plants to be observed is given. It includes 26 wild plants, mostly trees and shrubs, and 7 cultivated ones. Observations are required of the arrival and disappearance of a few designated species of birds and insects, and the time of heat of the deer and rabbit. The order in which observations were to be taken, the mode of recording, the methods of reduction, and all other details are minutely given in the instructions to observers, and painstaking care is required throughout.

From 1884 Dr. Lorenz-Liburnau put in operation some of the fertile ideas which he had already suggested. The three systems of radial stations were organized as already described. Dr. Liburnau thought that the general character of the influence of the forest on climate was already determined and that there was now required only the elaboration of details. The radial stations were designed to fix the relations of the forests to the climate of the vicinity with varying direction of wind, and a special series of observations were made to fix the relations of forest humidities and temperatures at various elevations, below, in, and above the tree tops, and to determine their modifications with general changes of the weather.

The most elaborate series of observations of this kind were those taken near Ried, in lower Austria, in 1887 and 1888. They were especially devoted to the problems of humidity, and to obtain thoroughly satisfactory results the ordinary wet and dry bulb thermometer was rejected and an exact chemical method substituted. This consisted in passing a known volume of air through calcium chloride and phosphoric acid and ascertaining by weight the water taken up by the latter. The case containing the chemicals was elevated, by means of a pulley on a mast, to the height at which the observation was to be taken, and the air was drawn through it by means of an aspirator below, connected with it by a rubber tube.

The observation occupied an hour and thirty minutes and the temperature was taken at the beginning and end by means of an upsetting thermometer, elevated by means of a pulley to the height required.

The results were very exact for the absolute humidity, less so for the relative. The heights at which the observations were taken were 4 inches (101.6^{mm}), 16 (4.87^{m}), 36 (10.97^{m}), and 51 feet (15.5^{m}). The second was under the tree crown, the third in it, and the fourth was 18 or 20 inches above it. The trees were red beeches, 60 to 70 years old, with a few white beeches and firs. The station itself was in and over the beeches.

SOIL TEMPERATURES.

The soil affords an excellent means of measuring the average temperature effects of the forest. This is due in part to the fact that the temperature of the air is not derived so much from the direct rays of the sun as it is from the heat reflected or radiated from terrestrial objects. These absorb the heat from the sun's rays more readily than does the air and yield it again to the air. The soil serves in another way also to average the effects of forests. The soil is more slowly warmed by the sun than is the air, and the deeper the stratum the more slowly it is warmed. The result is that rapid and passing changes of air temperature do not affect it, or affect it only superficially. It tends to show only the great periodic changes in temperature, and from it we are able to ascertain what influence the forest has on these changes.

The results which follow are always given in terms of the difference of temperature of the soil in woods and in open fields. If we put *W* for woods or forests and *O* for open fields, the data given hereafter* for

*NOTE ON THE CONSTRUCTION AND READING OF THE DIAGRAMS IN THIS REVIEW.— The horizontal lines (ordinates) above or below the zero line represent values or amounts, degrees of temperature, inches of precipitation or evaporation, percentages, etc. The vertical lines (abscissæ) represent time, dividing the field into twelve seasonal divisions corresponding to the twelve months of the year, the outer lines both standing for the month of December or commencement of winter. The curve lines are constructed by noting on each monthly line the values found for the month, and then connecting these points by either straight or rounded-off lines.

Unless otherwise noted, the values so plotted are the differences between the read-

temperature are always, except where otherwise stated, the values of $W - O$. A positive sign (+) indicates always that the woods are warmer than the fields; a negative sign (—), that the woods are cooler than the fields. The degrees are Fahrenheit and the other units of measure are the usual English ones, unless otherwise stated.

In Fig. 1 are given the mean annual differences of temperature for fields and woods at the surface and at the depths of 6 inches and 4 feet. These are for the German stations, a brief description of which may be found on page 30. They are arranged in the order of their differences at the surface, and at the right hand are given the average values. It will be noted at once that the differences vary much for the different stations. The mean annual difference for Hadersleben is less than one degree at the surface, while that at Melkerei or Neumath is nearly four degrees. It will also be noticed that the differences at 6 inches vary with respect to each other and also with respect to those at the surface. They are generally less than the surface differences at the same stations, but Hollerath furnishes a notable exception. On the whole they run with the surface differences, but are somewhat less. Again the differences at the depth of 4 feet differ among themselves, but not so much as do the others. Their relative uniformity is due to the depth at which the temperatures are taken, the smaller surface changes, in temperature and in water contents, being little felt. These differerences are usually greater than those at the depth of 6 inches and less than those at the surface. But there are exceptions to this, notably in the cases of Hollerath and St. Johann. These differences in the action of the forest are due to several possible causes, such as differences in soil as well in the field as in the forest station, in kind of trees, in their density, in the exposure, in the character of the air drainage.

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ings under two sets of conditions, namely, in most cases the values which were found for the stations in the woods (W) diminished by the values found for the stations in the open field (O), or $W — O$.

The value of this difference is positive, if the curve runs above the zero line—that is to say, the records for the woods (W) showed higher values than that for the open field (O); it is negative, *i. e.*, the record for the woods was lower, if the curve line runs below the zero line. The greater, therefore, the vertical distance of any point in the curve from zero line, the greater is the influence of the woods. In temperature readings, for instance, the curve above the zero line would denote that the woods were warmer; below the zero line, that the woods were cooler than the open field by as many degrees as the curve runs above or below the zero line, the latter representing that state of conditions when W = O, *i. e.*, when there is no difference in the readings for the two sets of conditions.

Where values for each set of conditions are plotted separately, the area included within the two curve lines (hatched) exhibits the difference between the woods and open field.

To exhibit more readily the amount of influence of the forest, the areas included by the zero line and the curve for mean values is also hatched in most cases.

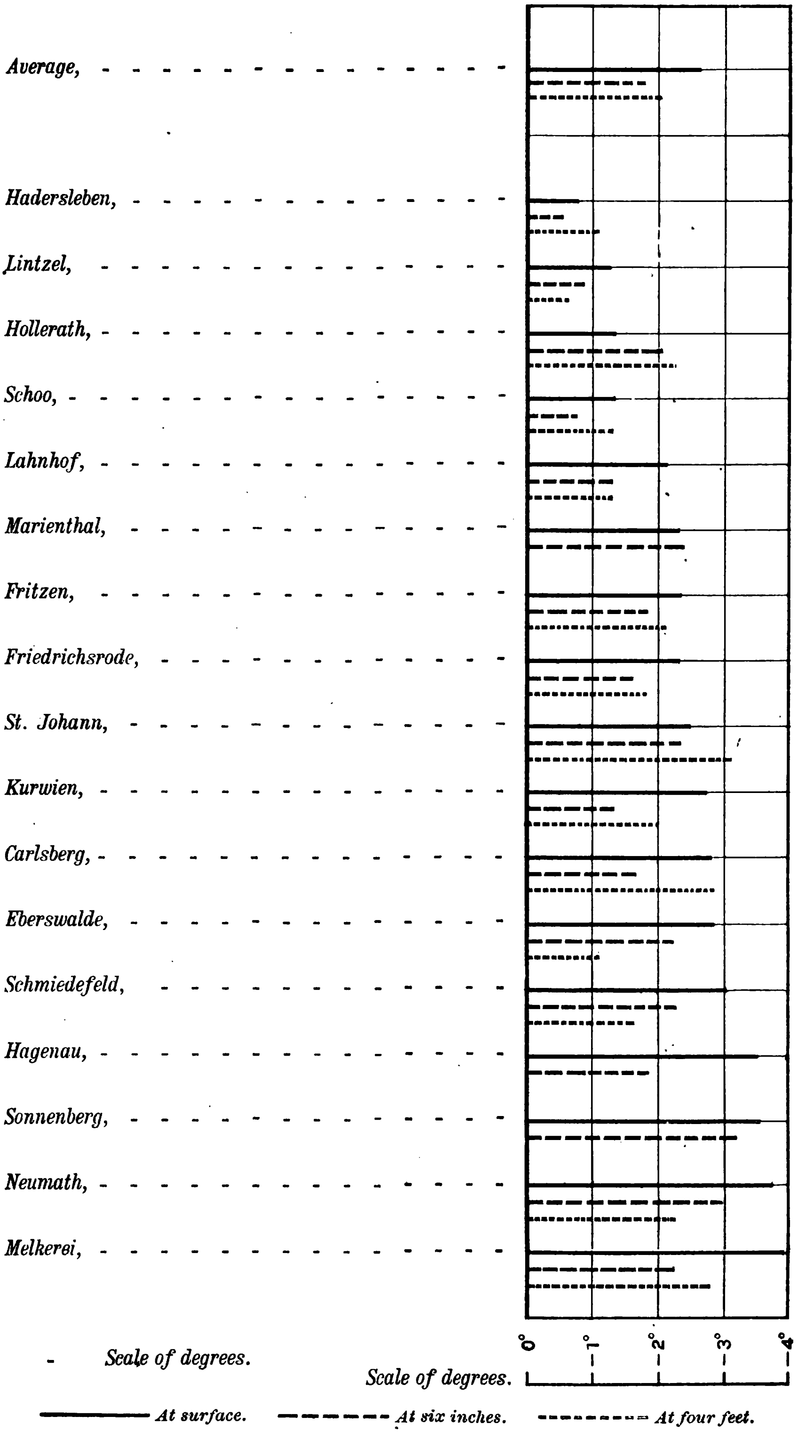


FIG. 1.—Differences of mean annual temperatures of soil ($W—O$).

Some of these will be discussed later; the material on hand does not permit the discussion of the others. They are instructive, however, in showing how great is the difference in action of different forests. For instance, the effect on the temperature of the surface at Melkerei (—3°.95) is nearly five times as great as at Hadersleben (—0°.84). This difference of action of the forest is far-reaching, for it extends through a layer of 4 feet of badly conducting soil. The difference at this depth at St. Johann (—3°.03) is about three times that at Eberswalde (—1°.06) or at Hadersleben (—1°.04), and is five times that in the young forest at Lintzel (—0°.58). The average of the seventeen stations (representing about two hundred years of observation) should give us good and significant results. It shows for the surface—2°.59, for a depth of 6 inches (152 mm.)—1°.87, and for a depth of 4 feet (1.22 m.)—2°.02. The influence of the forest on the soil, then, is a cooling one, on the average, and for central Europe the cooling amounts to about two and a half degrees for the surface. The cooling is due to several causes: The first is the shade; the foliage, trunks, branches, and twigs cut off much of the sun's heat, absorb and utilize it in vegetative processes, or in evaporation, or reflect it away into space. Thus the surface soil in the forest receives less heat than the surface of the fields. The same screen acts, however, in the reverse direction by preventing radiation to the sky, thus retaining more of the heat than do the open fields. The balance of these two processes, it seems from observation, is in favor of the first and the average result is a cooling one.

But the thatch of living foliage is not the only screen possessed by the forest soil. It has in addition the screen of the forest litter, and this is in a condition to be even more effective than that of living foliage. It lies in contact with the ground, preventing the dissipation of the heat of the soil by moving air, and at the same time lying so loosely as to form air spaces, which act as insulators in the way of preventing the exchange of heat between the forest soil and air. These cooling influences are enforced by the moist condition of the forest soils. It does not warm so easily as the drier field soil, and more of the heat which reaches it is used in evaporative processes than in that of drier soil. The balance of all these processes is, it appears, in the direction of cooling. And the cooler forest soil will cool, to some degree, the air in contact with it, and this air, flowing off to some other place, will take this cooler temperature with it, so that the coolness of the forest soil will make itself felt over the vicinity.

The differences of temperature at the depth of 6 inches (152 mm.) are more than half a degree less than at the surface. In this is to be seen the specific effect of the forest litter; it adds a covering to that possessed by the surface, so that while the deeper layer is cooled as much by the protection from the sun's rays as is the surface, it is not cooled so much by radiation of heat to the sky. Its temperature is, consequently, relatively higher, and it approximates somewhat more the field temperatures.

It is not so easy to explain why the difference at 4 feet averages a little less than at the surface and a little more than at 6 inches. It may be due to retardation in the penetration of diurnal temperatures into the soil. This may be slower in the cool, moist forest soil than in the warmer and drier soil of open fields. If this is the case observations at the same instant at the two stations would determine the temperature at two different parts of their curves. The diurnal changes probably extend to a greater depth than 4 feet, and if they

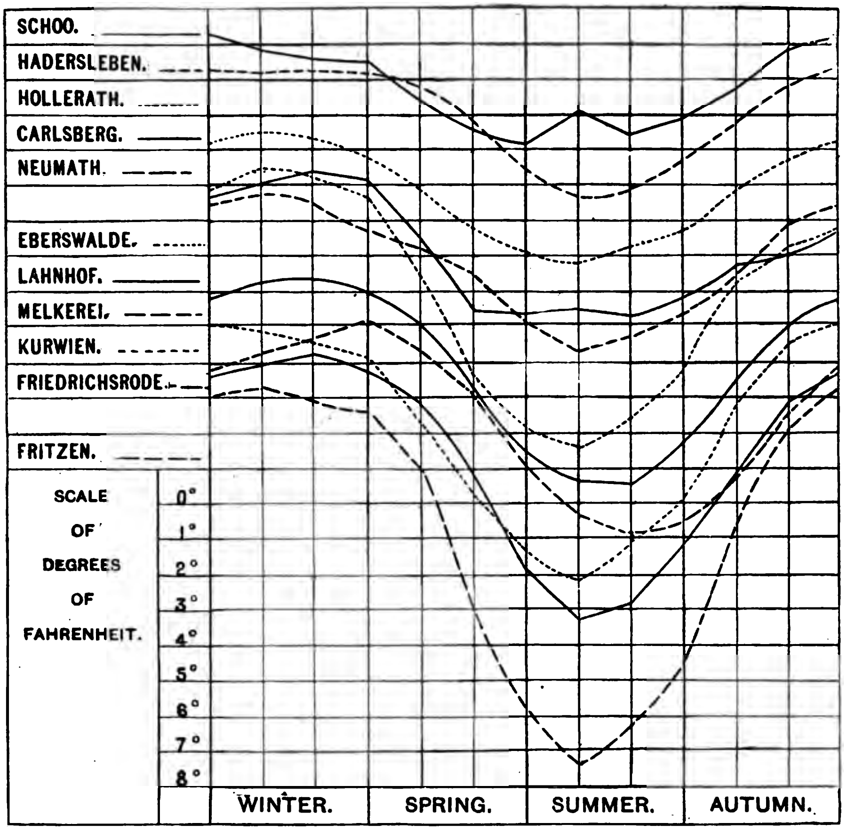


FIG. 2.—Difference of temperature (*W—O*) at the depth of 4 feet. (The line running under the name of a station is its zero line. The curve for the station is represented by the nearest broken, unbroken, or dotted line like that in the margin.)

have different times of maxima and minima (later in the forest) the increase of the difference at this depth could be explained. It may be that a part (undoubtedly a small one) of the differences at the surface and at 6 inches may be due to this. The observations were taken at 8 a. m. and 2 p. m.

Turning now to the progress of the difference, "Woods" minus "Open field" readings, through the seasons, or, as we shall generally express it, *W— O*, as shown by the differences of the monthly means, another series of interesting facts appear.

Fig. 2 shows the differences of temperature through the year at the depth of 4 feet. The curves for all the stations for which good monthly means for all the months could be obtained are put on one sheet for comparison. In order not to crowd them too much they are placed at different levels, the zero level for each station being represented by the line running under the name of the station, and the curves belonging to each station either unbroken, broken, or dotted lines nearest to its zero line. Seasonal lines are drawn for the monthly values, winter beginning with December, spring with March, summer with June, and autumn with September. The stations are arranged in the order of the greatest summer differences.

The distances between the horizontal lines representing degrees Fahrenheit, the absolute amount of $W-O$ can be read. Thus, for Eberswalde, during the month of December, $W-O$ is between two and three degrees, the soil in the forest being by that amount warmer than that in the open at 4 feet (1.22m) depth, while in the middle of July it is just five degrees lower.

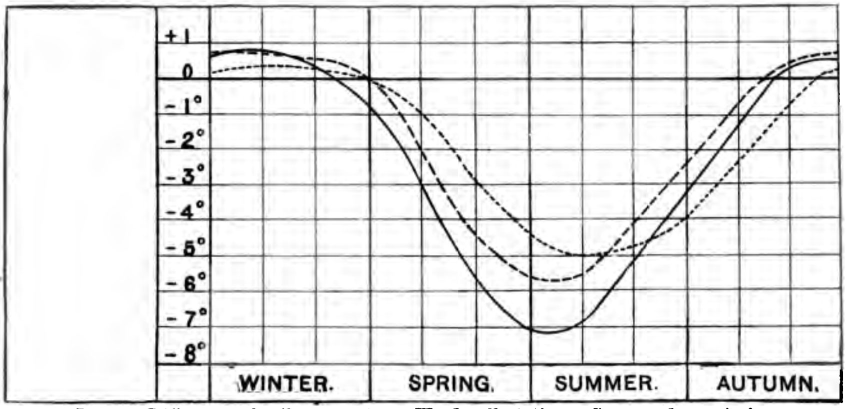


FIG. 3.—Difference of soil temperature ($W-O$), all stations—German observatories.

It will also readily be seen that the values for Hollerath, Carlsberg, and Neumath are never above their zero line; that is to say, are always negative, the soil in the woods being always cooler.

This figure shows in more detail the differences between the stations which were so readily apparent in the annual means. The time of maximum is generally July, but Schoo, in a mean of ten years, gives a secondary minimum at this time, and for Carlsberg and Melkerei the maximum difference falls in August. Most of the stations give a positive sign for $W-O$ in winter, some of them showing a large excess (Eberswalde+2°.41, Fritzen+2°.20); but there are several exceptions, and all those which do not cross the zero line come very near to it. The maximum monthly difference is —8°.17 for Fritzen in July. The least July value is —1°.93 (for Schoo), less than a quarter of the preceding.

The sign of $W-O$ generally changes from negative to positive in December, and the reverse in March. The progress of these curves is

nearly alike, and on constructing the curve for the average this appears smooth and symmetrical, as is seen in Fig. 3. The dotted line here represents the progress of the differences at the depth of 4 feet. All the irregularities have here disappeared. The temperature is seen to be warmer in the woods than outside during the entire winter. It then falls rapidly during the spring, reaches its lowest point about July 1, and rises again rapidly during the autumn. The broken lines represent the progress of the differences of temperature at the depth of 6 inches and the unbroken that at the surface. The first have the smaller maximum values and also indicate a longer time during which it is warmer for woods. The maximum monthly differences are: For 4 feet, —5°.01 in July; for 6 inches, —5°.48 in June; for the surface, —7°.05 in June.

A glance at the curves shows more strikingly the retardation suggested by these values. By the course of the curves it appears that the maxima are successively later as we descend, being a full month later at 4 feet than at the surface. Probably the same thing occurs with diurnal changes; that is, they are retarded by some hours at the lower depth. It appears from these curves that, on the average, the forest soil is warmer than that of the open fields in winter, but cooler in the other seasons, and the total cooling effect is much greater than the warming one. The numerical data show that while the maximum negative value of $W - O$ at the surface is 7°.05, the maximum positive value (January) is 0°.66, or only about one-eleventh of the former. At 6 inches (152.4 mm) the numbers are 5°.48 and 0°.62, and the ratio one to nine. At 4 feet (1.22 m) they are 5°.1 and 0°.36, or a ratio of one to fourteen. The forest, therefore, not only cools the soil, but also moderates the extremes of its temperature. The amplitudes of the mean monthly values are decreased by 0.66 + 7°.05 = 7°.71 at the surface, 0°.62 + 5°.48 = 6°.10 and 0°.36 + 5°.01 = 5°.37 at 6 inches and 4 feet depth, respectively, and through the soil this moderating influence must be appreciable in the air.

The stations of the German service are so happily distributed that a study can be made of the differences in the influence of deciduous and evergreen trees upon soil temperature, and also those for elevation above the sea. For the first, seven stations under deciduous trees and seven under evergreens were taken, Fritzen and Eberswalde being omitted to get a symmetrical arrangement, and Lintzel, because the trees were young. The reductions were made for the two sets of stations independently, and the results are shown in Fig. 4. The results are here plotted separately for the surface, for 6 inches, and for 4 feet. The dotted lines refer to the deciduous trees, the broken ones to the evergreens. The differences are not great, but they are quite consistent at the three depths. They may be expressed by the statement that the differences vary a little more under deciduous trees. This is what should be expected from the character of their foliage. The same

explanation would suffice for the slight retardation of the fall of the curve for deciduous trees. There is one feature, however, that is unexpected. It is, that the difference between the two sorts of forests is not especially marked in winter. As a matter of fact, in the high latitudes in which the observations are taken, the sun is so low in winter that the bare trunks and branches are fairly efficient screens against his rays.

The darker color of these bodies also permits them to be more warmed up when the sun does appear. Besides, the persistent cloudiness of the winter and the covering of snow in these latitudes tend to equalize the effects of the soil of these two types of forests at this season. The annual means for the two kinds of forest differ but little.

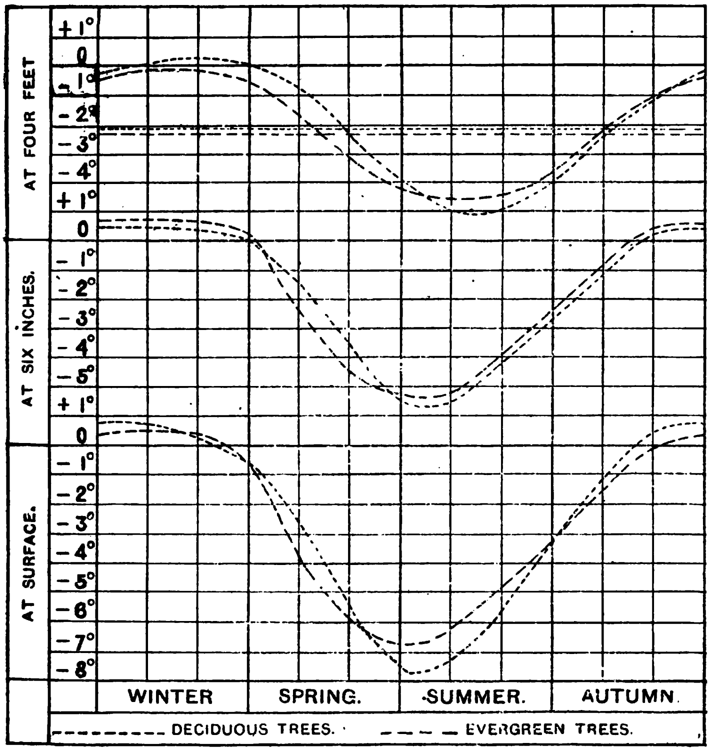


FIG. 4.—Differences of soil temperature (woods and open fields). Comparison of deciduous and evergreen trees (*W—O*).

For the surface they are —2°.57 for deciduous trees, —2°.62 for evergreen trees; at 6 inches they are —1°.89 and —1°.82; at 4 feet—2°.05 and —2°.19. They are represented in the diagram for the 4-feet depth by the two straight lines, to show the slight difference between the two types of forest cover. The difference in amplitudes is somewhat greater. The amplitudes are:

	Surface.	Six inches.	Four feet.
For deciduous trees	8°.50	6°.04	5°.12
For evergreen trees	7°.31	6°.04	4°.37

As to the effect of elevation above sea-level, there are seven stations over 1,900 feet (579 meters) and seven below 500 feet (152 meters). The mean elevation of the first set was about 2,400 feet (732 meters), that of the second about 240 feet (93 meters). Lintzel was omitted, and evergreen and deciduous trees were about equally distributed in the two sets. The reductions were performed for each of these sets separately, and the results are shown in Fig. 5. The differences are a little more marked than in the case of deciduous and evergreen trees. The range is

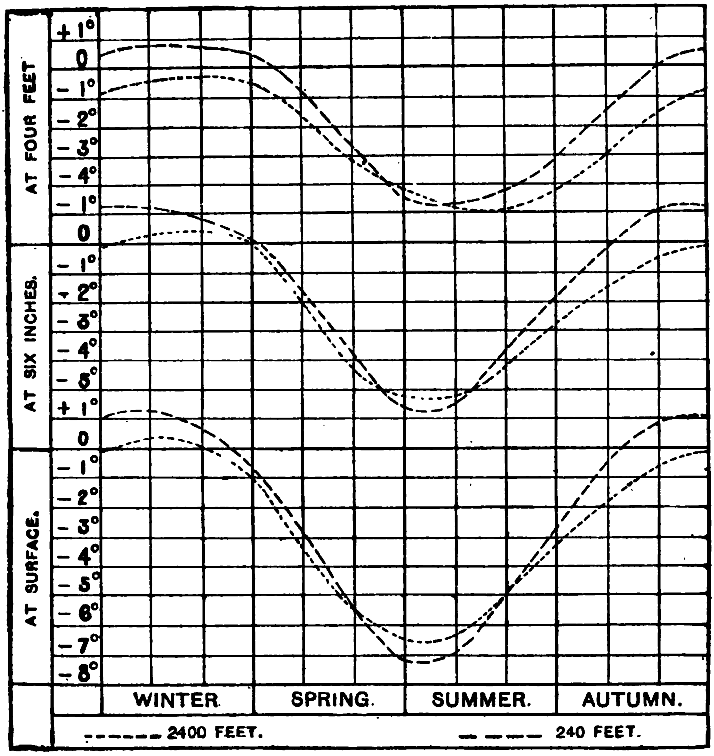


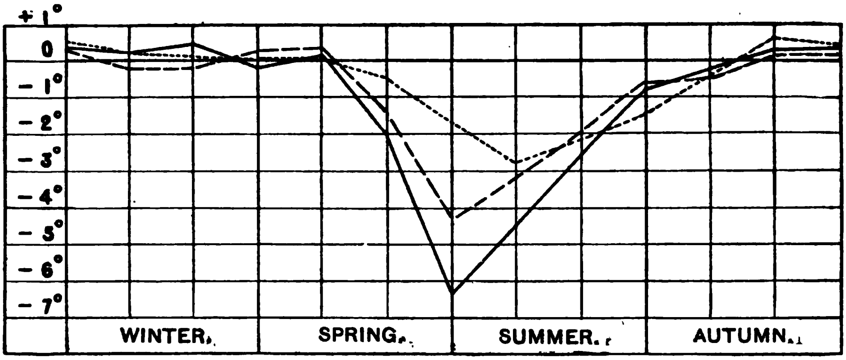
FIG. 5.—Differences of soil temperature (woods and open fields). Comparison of elevations above sea level (*W—O*).

noticeably smaller at the higher levels. The forest cover there has a greater cooling effect in summer and a greater warming effect in winter. Its influence in moderating a climate is, consequently, slightly greater.

The difference in influence of young trees and old is also of interest, but the material is scanty. Lintzel is a station among young trees, but there are only seven years of observation (including 1888, the latest on hand at this writing). The curves are given in Fig. 6, and their lack of evenness betrays the brief series of observations from which they were drawn. The surface summer reduction seems very large, and that at 4 feet unusually small, but these results may be due rather to the soil at the station (Lüneburg heath) than to the trees. Dr. Wollny has

made some studies of the effects on soil temperatures of vegetation at different heights and has found that on the whole they increase with the height.

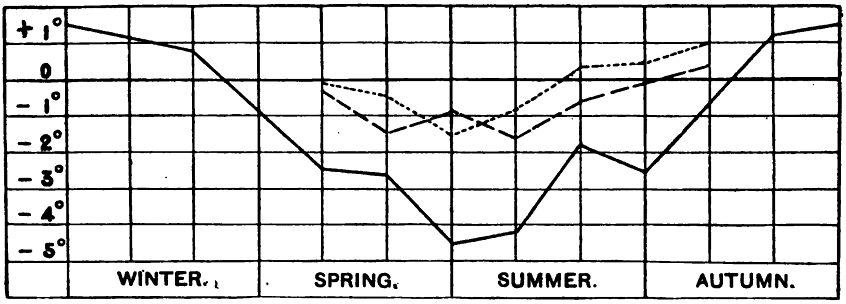
That the forest litter plays an important part in the matter of soil temperature can not be doubted, but no details are given on this point in the published reports of the forest meteorological services. Numerous experimental observations have, however, been taken by Dr.



——— *At surface.* — — — *At 6 inches below surface.* ······ *At 4 feet below surface.*

FIG. 6.—Differences of temperature for young trees, Lintzel Station, woods and open fields (*W—O*).

Wollny, the results of which are graphically exhibited in Fig. 7. The unbroken curve is here the result of several years' observation; the broken ones represent shorter series, made to test the effects in individual soils. The comparison is always made with bare soil, and the positive sign here means a higher temperature in the covered soil. The general trend of the curves is strikingly like that in forests.



——— *Average results.* — — — *Results on loamy soil.* ······ *Results on quartz soil.*

FIG. 7.—Effects of litter on soil temperature (littered surface—bare). (*W—O*).

The material at hand does not permit the study of other modifying influences—soil, latitude, prevailing cloudiness, water in the soil, etc. As a means of comparison, it may be of interest to give the progress of soil temperatures under sod as compared with that under bare soil. This is given in Fig. 8, which represents the means from an eleven-year series of observations by the MM. Becquerel. The trend of the curves is quite unlike that of the forests. The sod is relatively warmest in autumn and coldest in spring, and the mean is in favor of warmer

rather than cooler temperatures. The curve is constructed on the same scale as all the other figures of this chapter. The small May indentation is very curious and is unexplained.

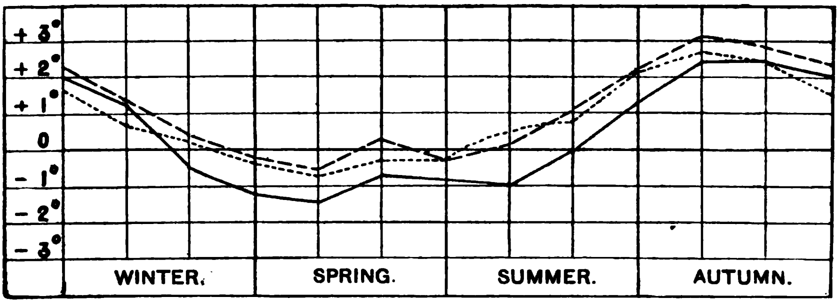


FIG. 8.—Difference of soil temperature, under sod, and bare surface (sod—bare). Becquerel's observations.

From the report of Mr. Fernow for 1889, the following tables are here reproduced, combining results of various sets of stations in different parts of Germany; the temperature is given in centigrade, the minus sign denoting lower temperature in the forest, the plus sign higher temperatures.

Differences of temperature of the soil inside and outside of a forest.

	February–April.		May–July.		August–October.		November–January.		Year.	
	Surface.	0.9 m.	Surface.	0.9 m.	Surface.	0.9 m.	Surface.	0.9 m.	Surface.	0.9 m.
Alsatian Mountains	—1.0	+0.5	—7.8	—2.8	—5.7	—3.2	+0.3	—0.7	—3.5	—1.5
Bavaria	—1.8	—0.8	—4.5	—3.9	—2.6	—3.0	0	—0.1	—2.2	—2.2
Bavaria (other stations)	—1.3	—0.6	—4.6	—4.1	—2.6	—3.0	+0.3	—0.1	—2.1	—2.0
Eastern Prussia	—1.3	0	—4.4	—3.6	—2.3	—2.2	+1.3	+0.9	—1.6	—1.2

The mitigating influence on the soil temperature appears still more clearly when the maximum and minimum temperatures for the year or the range of temperature is compared.

	Range of temperature.	
	Without the forest.	Within the forest.
	Degrees.	*Degrees.*
Bavaria	39.5	29.5
Alsatian Mountains	35	21
Eastern Prussia	41.8	26.7

TEMPERATURES OF AIR IN THE INTERIOR OF FORESTS.

We pass now from the soil, which is fixed and the temperature changes of which are due to the changes of the surrounding medium, to the constantly moving air, the temperature changes of which are to some extent due to the motions of the medium itself. The results for the air from this cause are less definite, more variable, and more capricious than those derived from observations on the soil. At the surface of the soil there is only an imperfect relation between the temperatures of the soil and air. Yet it is undoubtedly true that the air temperatures near the surface are due in the first place to heat derived from the soil. It is to the motion of the air, carrying with it its temperature, that this disparity between soil and air temperatures is due.

The observations used here are those of maximum and minimum temperatures.* These afford satisfactory results, because what we are concerned with is not so much the temperatures in woods as the differences between temperatures in woods and those outside. Besides, in using the extreme temperatures, all danger is avoided of being misled by a difference in the diurnal progress of temperatures at the two stations. The extreme temperatures, also, are those which best show the influence of the forest, for this is exercised chiefly here, as in soil temperatures, in reducing the extremes. The data used are always, unless otherwise stated, the values of $W-O$ (woods minus open fields reading), and it is to be remembered that a minus sign (or position below zero line) indicates colder temperatures in woods, a plus sign (or position above zero line) warmer. The observations are taken at the same height from the ground in the woods and outside.

ANNUAL RANGE.

Fig. 9 shows at a glance the mean annual values of the temperature difference of $W-O$ in the case of maxima, minima, and the mean derived from them. The heavy line across the figure represents the zero line (for $W-O=0$). The annual values for $W-O$ for the maxima are always negative and they are laid off to scale below the zero line. The annual values for $W-O$ for the minima are always positive and they are laid off above the zero line to the same scale.

It appears at once that the action of the forest varies greatly in the different stations. It always cuts down the annual mean of the monthly maxima, but to a very variable extent. In the case of St. Johann (five years of observation) it cuts off the maxima by an average of 4°.89, but in the case of Schoo it is only 1°.44, or less than one-fourth, and in the case of the young forest of Lintzel, it cuts down the maxima by only 0°.35. The average amount of reduction for all stations is 2°.85.

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*Dr. Müttrich has published a complete reduction of the air temperatures for the German service up to 1890. It may be found in Danckelmann's *Zeitschrift für Forst und Jagdwesen*, XXII, 1890, 396 and 397.

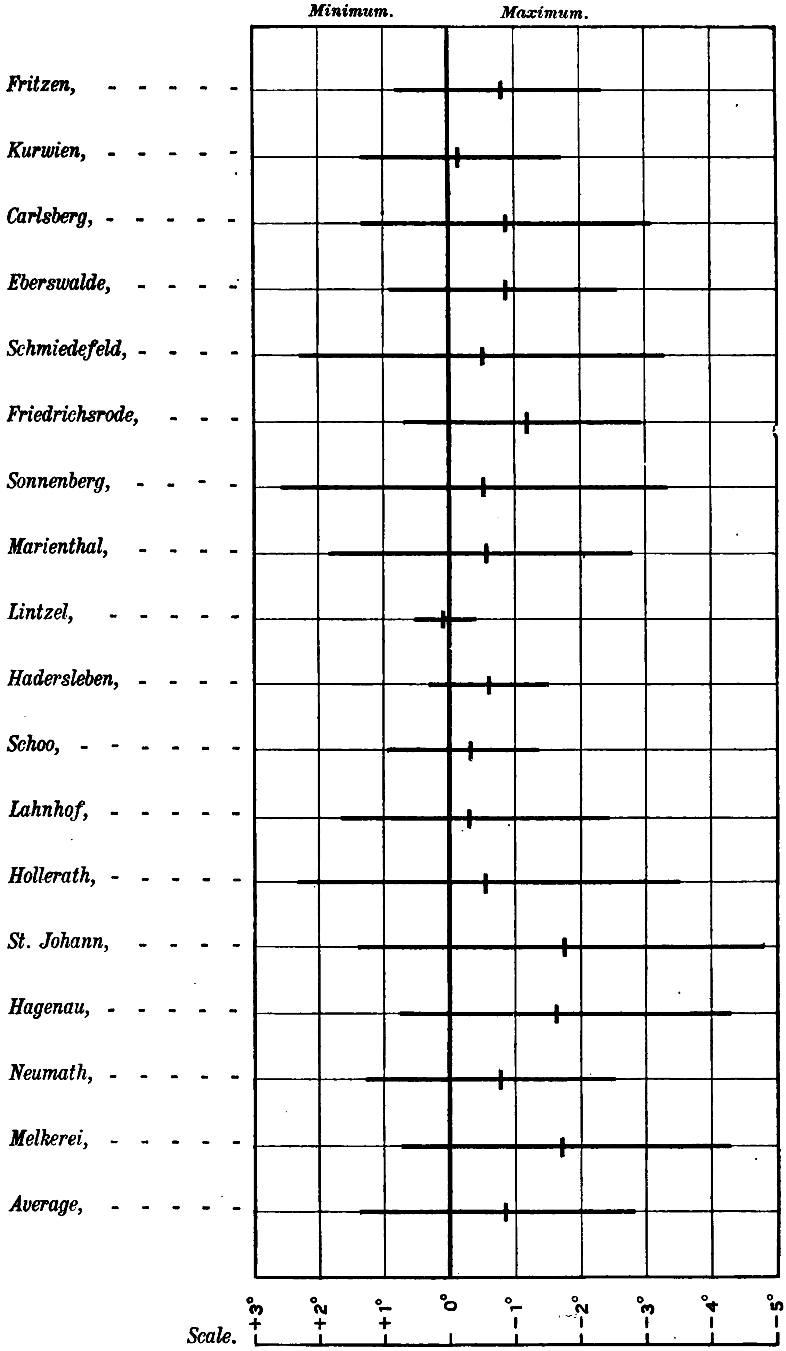


FIG. 9.—Forest air temperature differences ($W-O$). German stations. Mean annual (cross-bar), maxima (below zero line), minima (above zero line), and range (length of lines).

Very much the same is true of the minima temperatures. They are always cut off in the annual mean, but by a varying amount. The largest reduction of the minima is for Sonnenberg (2°.56); the smallest is for Melkerei (0°.74), except for the young forest of Lintzel station, where it is only 0°.43. The average amount is 1°.33.

The length of the lines opposite the names of the stations in Fig. 9 indicates the reduction of the range in temperature in the woods as compared with the outside. This is a reduction of range, because the forest lowers the highest temperatures of the day and raises the lowest. This reduction varies like the preceding, of which it is the sum for each station. For St. Johann it is 6°.25, for Sonnenberg 5°.92, while it is only 1°.86 for Hadersleben and 0°.78 for Lintzel. This is a measure of the degree by which the air temperature is moderated in the woods in the average. The absolute moderation is often greater, as the woods become more efficient in reducing greater extremes, especially in lowering the highest temperatures. This is seen by considering the absolute range for the year—that is, the number of degrees between the highest temperature for the year and the lowest. The mean of the absolute annual ranges at all the German stations is for the open fields 92°.90, for the woods 81°.86, which gives a reduction of 11°.04. The mean range for all stations is 4°.18, or but a little more than a third of this. The value of *W—O* for the mean annual temperatures is one-half of the sum of the value of *W—O* for the maxima and minima. The reduction of the minima is always less (except for Lintzel, young woods) than the reduction of the maxima, and the combined effect is necessarily a cooling one. On Fig. 9 the position of the mean temperature compared with the zero line is the point in the middle of the line representing the range of *W—O* for each station. This is marked by a short cross line. It will be observed that in every case, except the one mentioned, this mark falls below the zero line, or on the cooling side.

The amount of reduction of the mean temperature varies with the reduction of the extremes, and is very different for different stations. For St. Johann it is 1°.76, for Melkerei it is 1°.72, but for Kurwien it is only 0°.17, while for Lintzel the mean temperature is 0°.04 higher in the woods than out. The average reduction of mean annual temperature for all the German stations is 0°.76.

It appears, therefore, that *the forest moderates* (by reducing the extremes) *and cools* (by reducing the maxima more than the minima) *the temperature of the air within it. The moderating influence is decidedly greater than the cooling effect.*

MONTHLY RANGE.

On taking up the consideration of the mean monthly values of *W—O* a very curious series of results appears. Fig. 10 illustrates the influence of the forest on the temperature of its interior air at Friedrichs-

rode, but is a type of all the curves, differing chiefly in the magnitude of the changes it indicates. The line of zero differences is used as the base line of the diagram. On it are laid off, at equal distances, seasonal lines, on which the values of $W-O$ for the monthly minima are measured off, above the zero line if plus, below if minus. The points thus obtained are connected by the dotted line above and this, therefore, is the curve representing the reduction ($W-O$) of the minima. In exactly the same way are constructed the curves for the mean monthly values for $W-O$ for maxima, represented by the broken line, which is, therefore, the curve for the reduction of the maxima for the year. Between these two curves is drawn a curve with unbroken line, which represents the reduction ($W-O$) for the mean temperatures. This figure shows at a glance all the details concerning the influence of the forest on its own interior air temperatures. The distance vertically between the exterior curves is the reduction of the range. The space between the middle curve and the zero line represents the change in mean temperature due to the influence of woods, cooling if the curve lies below, warming if it lies above, the zero line. Where it lies below, the space has been shaded to show plainly the amount of cooling. In this diagram, therefore, is shown the progress of all these elements during the year. Analyzing the progress for Friedrichsrode (Fig. 10) we see that the minima in the woods do not differ much from those outside between November and April. Then the forest begins to affect them and the curve for $W-O$ for minima rapidly rises above the zero line. It reaches the greatest distance in August, approaching the line again from September to November, when the minima are once more closely alike in the forest and outside. The forest has the greatest effect on the minima in summer, somewhat less in May and September, still less in April and October. For the values of $W-O$ for maxima the progress is much the same, only in the reverse direction and two or three times as great in magnitude. The greatest effect here falls in July instead of August. It gives form to the $W-O$ values for mean temperature, for which the greatest value falls in July. It appears also that the temperature in the woods is almost always lower than in the open fields. In March it is about the same; in winter it is a little cooler; in summer it is decidedly cooler, especially in July.

These figures for $W-O$ are variously modified in the various stations. Fig. 11 (Hagenau) shows a case where the reduction of the minima, especially in summer, is relatively small, and the mean temperature of the woods is less for the entire year. Fig. 12 (Sonnenberg) represents a case where the reduction of minima is almost as large as that of the maxima and there is little reduction in mean temperatures. In fact, the woods here are warmer in winter. In Fig. 13 (Eberswalde) the reduction of mean temperature is small and continues during the year, like the preceding, but for a different reason the reduction of maxima and minima here run symmetrically, but shows no great difference in quantity.

Forest air temperature differences, woods and open fields (W—O).

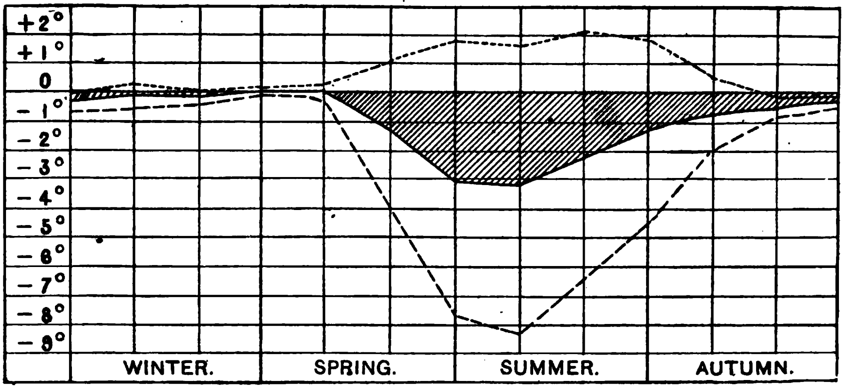


FIG. 10.—Friedrichsrode.

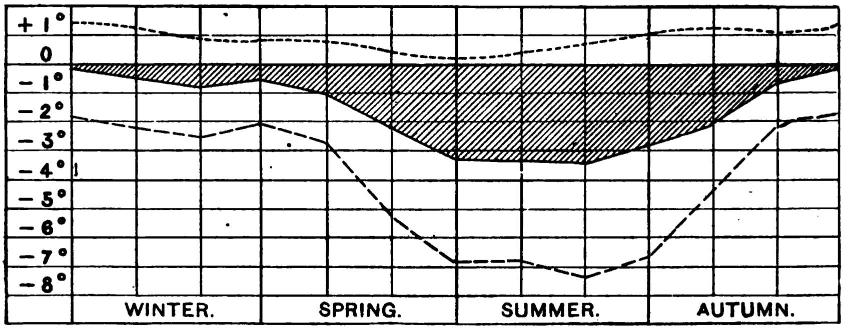


FIG. 11.—Hagenau.

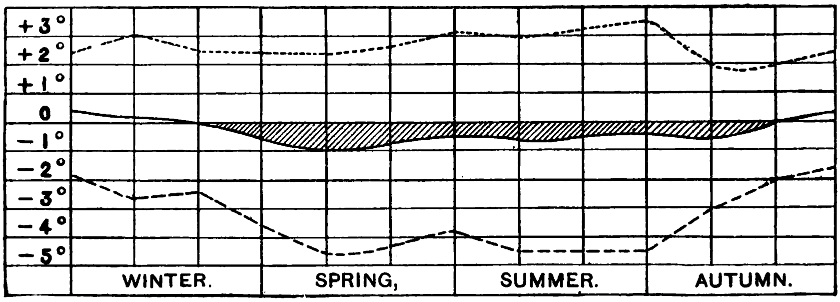


FIG. 12.—Sonnenberg.

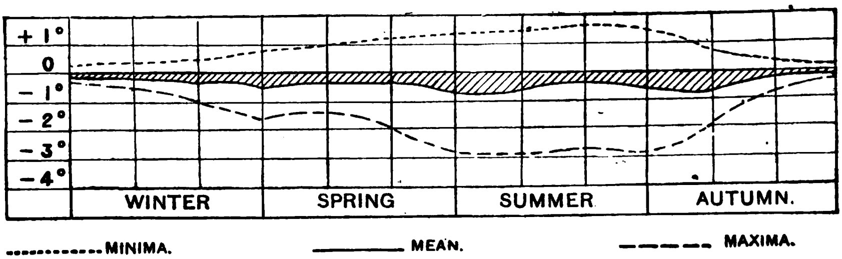


FIG. 13.—Eberswalde.

Fig. 14 (Schoo) shows a small reduction of mean temperature limited to late summer and early autumn. Fig. 15 (Marienthal) shows a curious aberrant case. The woods in March and April are warmer than the fields. But Fig. 16 (Hadersleben) is perhaps the most curious of all. Here the maxima of temperature are higher in the woods from November to April than they are in the fields, and during the same time the minima are lower. The temperature range through these months is, therefore, greater in woods than outside. But the increase in range is small and the mean temperatures are about the same in woods and outside.

These figures, all of which, except the first, have been selected because they were peculiar, are instructive in showing how extremely forest action varies while preserving consistently its characteristic features. The variations are due to the causes mentioned under soil temperatures, with the addition, in this case, of disturbances due to prevailing winds. The average effects in which these disturbing actions are eliminated more or less completely are illustrated in Fig. 17. As this represents the result from sixteen stations, through about two hundred years of observation, it may be considered fairly typical for middle latitudes. From this diagram it appears that—

(1) As to minima, the forest reduces them with fair uniformity during the entire year. For about half of the year they are reduced about a degree Fahrenheit. In April this reduction begins to increase; it grows gradually until it reaches a maximum of about 2 degrees in August. From this it lessens until November, when its average value is 1 degree.

(2) As to the maxima, these are reduced about 1 degree in December. This reduction grows slowly until it reaches about 2 degrees in April. From this it grows very rapidly until it reaches about 5 degrees. It remains at about this value during the summer and decreases rapidly during the autumn to its December value.

(3) The reduction of range is about two degrees in the winter, six or seven degrees in the summer, and an intermediate amount in spring and autumn.

(4) As to mean temperature, it is one or two degrees cooler in the woods in summer, about the same in woods and open fields during the winter and intermediate in spring and autumn.

(5) The moderating and cooling effects of woods already mentioned as a phenomenon of mean annual temperature, extend, it appears, through the entire year, but they are especially marked in summer. The cooling effect tends to disappear in winter. The moderating effect is the most important one and it is the most characteristic.

It has often been claimed that forests warm the air of their interior in winter, but the German observations do not show this. On the other hand, there is an occasional warming effect in early spring, while in winter the woods are usually slightly cooler than the open fields.

Forest air temperature differences, woods and open fields (*W—O*).

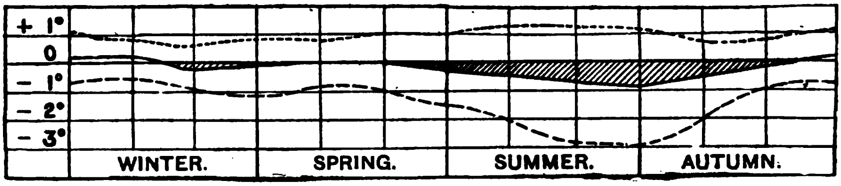


FIG. 14.—Schoo.

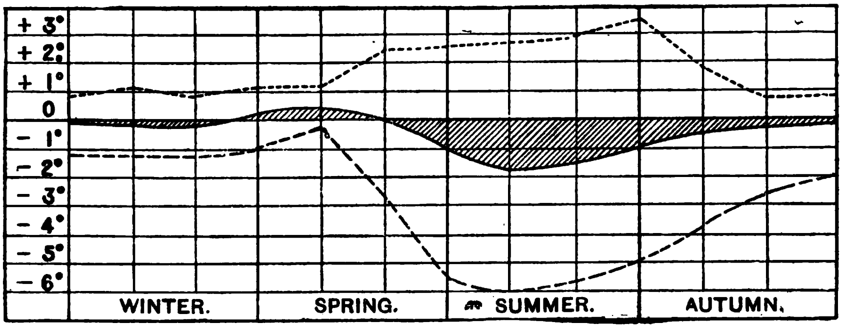


FIG. 15.—Marienthal.

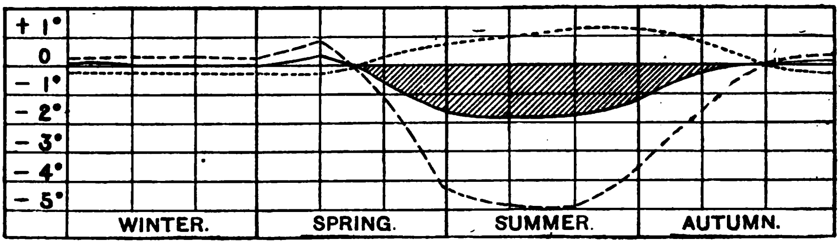
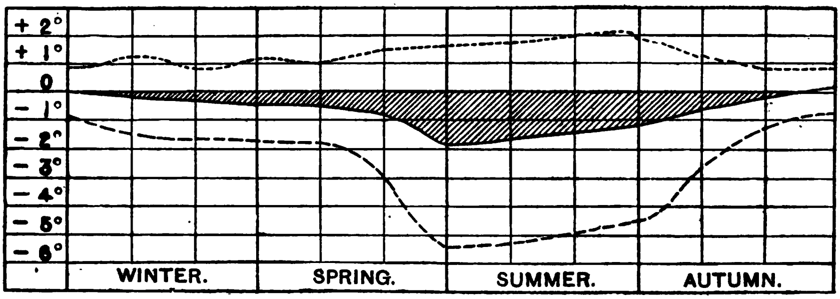


FIG. 16.—Hadersleben.



---------- MINIMA. ——— MEAN. — — — — MAXIMA.

FIG. 17.—Average.

M. Becquerel found in his observations that the woods were decidedly cooler during persistent cold weather. For instance, at La Salvionnière during unusually cold weather, from the 24th to the 30th of December, 1867, the temperature in the woods was 21.4° while that outside was 22.0°. From the 1st to the 12th of January, 1868, the temperature in the woods was 14.5° while that outside was 15.8°. For the stations near Chatillon-sur-Loing, at which Becquerel took his observations, the forest temperature for the latter dates average 13.3° while the temperature in open fields was 14.4°. He noted this in other cases and thought that the lower the temperature in extreme cold weather the lower relatively it was in the woods. This is, however, not always the case. In Dr. Ebermayer's published series of observations there is only one case out of seven where the extreme temperature was lowest in the woods and this was only by a little over one degree. On the other hand, at Seeshaupt, on January 25, 1868, the temperature in the fields was —20.4° while in the woods it was only +2.1°, or a difference of 22.5° in favor of the woods. These are extreme and not mean temperatures, but the published data do not permit the study of the daily mean temperatures. Rivoli made a special study of this subject and came to the conclusion that the relative winter cold of forests was quite dependent on the direction of the wind. In Posen, 146 single observations from November to March gave a warmer temperature in the woods except for south and southwest winds, when the forest temperature was lower by a fraction of a degree.

The published observations are not complete enough to give a good idea of the diurnal progress of temperatures under trees, but several students of the subject (Becquerel, Rentzsch, Bergen) find that it is of the same character as the annual progress. They generally represent the daily minimum temperatures of woods as being higher than those outside.

DECIDUOUS AND EVERGREEN FORESTS.

The German observations permit a study of the effects of different kinds of trees. The stations were classified for deciduous and evergreen forests as in the section on soil temperatures, and the means of the values of $W - O$ were calculated separately for each. The results are graphically represented in Figs. 18 and 19. The difference between them is much more striking than was the case with soil temperatures. The evergreen trees show a symmetrical increase in the reductions of maxima and minima until late summer, when they rapidly and symmetrically decrease. The greatest reduction of the maxima is 4.21° (August), the least 1.20° (December). The average reduction of maxima is 2.92°. The greatest reduction of minima is 2.20° for September, the least 1.29° in November, but it runs capriciously from 1.29° to 1.68° from November to May.

Forest air temperature differences of woods and open fields (W—O).

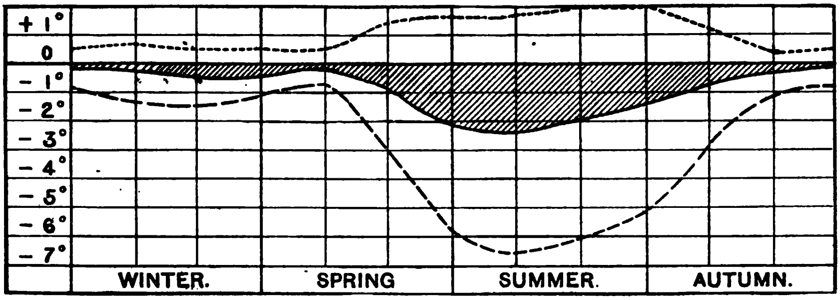


FIG. 18.—Deciduous trees.

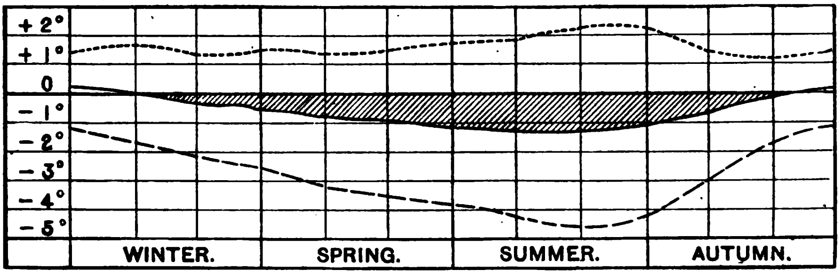


FIG. 19.—Evergreen trees.

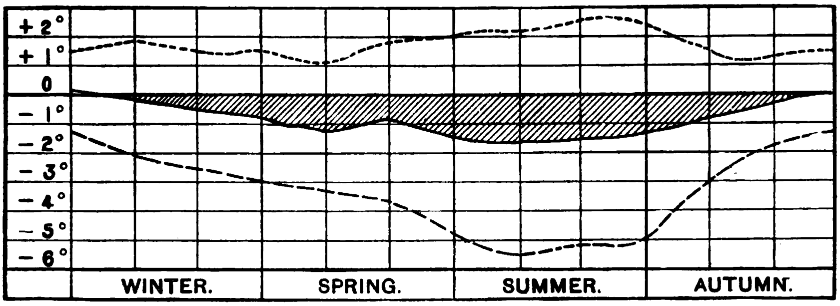


FIG. 20.—Elevated stations.

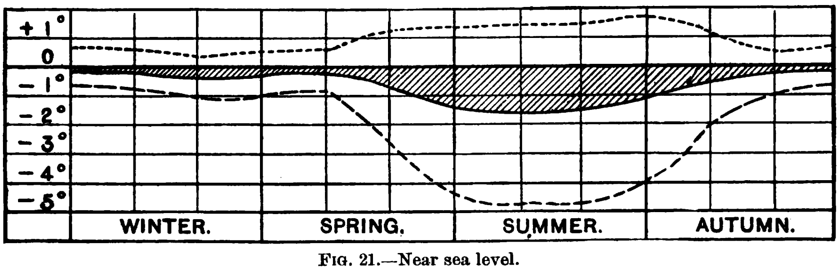


FIG. 21.—Near sea level.

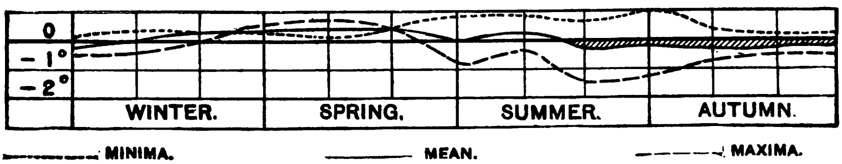


FIG. 22.—Young forest (Lintzel).

The mean annual reduction of the minima is 1.66°. The cooling of the woods takes place throughout the year, greatest (about one degree) in summer, least (almost nothing) in December and January.

On the other hand, under the deciduous trees the time of appearance and disappearance of the foliage is very plainly observable in the temperatures. The year starts out with them as with the evergreen trees, but in early spring the influence of the forest shrinks and tends to disappear. With the appearance of the leaves, in May and June, it grows again and very rapidly, so that the greatest effect is brought on in two months; through June and July it remains constant, but in August it begins to shrink rapidly, and by November it has again approached the degree of influence exhibited under the evergreen form. The greatest effect on the maxima is observed in July, when the reduction amounts to 6.50°, the least in April, when it is only 0.65°. The average is 2.92°, exactly that for evergreens. The reduction of the minima is greatest in September (2.03°), least in February (0.50°) and November (0.53°). The average is 1.14°—half a degree less than for the evergreens. The mean reduction of minima under deciduous trees is 0.89°, under evergreens 0.63°. The mean reduction through the year is curiously alike for evergreens and deciduous trees. The main difference is found in the values of $W - O$ in spring and summer. In early spring the deciduous trees have a scarcely appreciable effect on the temperatures; in summer their effect is to lower the temperature two degrees or more, about twice that of evergreens.

As to the effect of elevation above the sea, the stations were classified as in the section on soil temperatures and the results are represented in Figs. 20 and 21. These figures do not differ essentially. The effects on the elements are somewhat greater at the higher station and the cooling caused by the forest extends through the year more evenly. The difference is, however, very slight when expressed in terms of the reduction of the mean temperature. For elevated forests the reduction is 0.84°, for those near sea level, 0.66°.

It will be of interest to see what is the effect of a young forest on the temperature in it. Fig. 22 gives the results for Lintzel. The series of observations was only seven years long and this is not long enough, it appears, to give good even curves. It is curious to see that this curve hardly suggests those found for mature forests. The minima are always reduced, but the maxima are exaggerated in spring. Besides the reduction of mean temperatures has almost disappeared and is confined to late summer and autumn. As a matter of fact this is hardly a case of temperatures under trees. It is rather a case of temperatures in the foliage and corresponds to temperatures in tree tops in mature forests.

In the following table, taken from Mr. Fernow's report for 1889, the maximum, minimum, and mean temperatures at various forest stations are compared, the plus sign denoting higher the minus sign lower temperatures than those observed in the field stations, in centigrade readings:

	February-April.			May-July.			August-October.			November-January.			Year.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
Central Italy*	.....	.....	.....	−4.1	+1.6	−1.2	−3.6	+1.1	−1.3	.....	.....	.....	.....	.....	
Eastern France†	−0.8	+0.8	0	−3.2	+1.2	−1.0	−2.6	+1.3	−0.6	−0.9	+0.6	−0.1	−1.9	+1.0	−0.4
Alsatian Mountains‡	−1.1	+1.9	+0.4	−2.5	+1.9	−0.3	−1.9	+2.4	−0.2	+0.9	+1.7	+1.3	−1.2	+2.0	+0.4
Bavaria§	−0.5	+0.2	−0.3	−2.2	+1.1	−0.9	−3.2	+1.6	−0.8	0	+1.2	+0.6	−1.5	+1.0	−0.3
Eastern Prussia‖	−0.7	+0.1	−0.3	−1.4	+0.5	−0.4	−1.6	+0.2	−0.7	−0.3	−0.2	−0.2	−1.0	+0.2	−0.4

*Station Vallambrosa, Tuscany. †Station Bellefontaine, near Nancy.
‡Station Melkerei, in the Vosges Mountains. §Stations Seeshaupt and Rohrbrunn.
‖Stations Fritzen and Kurwien.

TEMPERATURES IN THE TREE CROWN AND ABOVE TREES.

The observations used in the preceding section were all taken at the usual height, that is, about 5 feet (1.5 m). The Swiss forest observations are taken at a height of 3 meters or about 10 feet. I have not been able to consult these observations except for a single year, that of 1876. In Lorey's Handbook of Forestry there are given seasonal means for twelve years from three stations, Interlaken, Pruntrut, and Berne. These give, in Fahrenheit degrees, for winter, *W—O* 0°.92 for spring, 1°.33; for summer, 2°.72, and for autumn, 1°.57. These are of the same general character as those taken at an elevation of 5 feet. The large value of *W—O* for spring makes them resemble more the values given in the preceding section for stations at high elevations above sea level. This is to be expected, as the Swiss stations are at the elevation of 2,034 (620 m.), 1,476 (450 m.), and 1,946 feet, (593 m.) respectively. Observations are also taken by the Bavarian and German services in the tree crown. A place is selected in the top of the tree, but under the thatch of foliage. This is as nearly as practicable vertical over the instruments placed at the surface, and observations on temperature are here made at the same time as at the surface. The discussion of these observations lies under two serious disadvantages. In the first place, there is generally no station at the same elevation outside the woods, and, in the second, the tree-top stations are necessarily at different heights, thus making impossible a direct comparison between stations.

The first difficulty may be overcome by making a fictitious outside station and giving the ground station temperatures a correction for known mean variations of temperature with altitude. Unfortunately this reduction of the surface observations to a given altitude can not be made without considerable uncertainty. The change of temperature with altitude alters with almost every source of meteorological change, with season and time of day, with the topography, the character of the soil and its covering, and with the weather, and the amount of change is especially variable within the first 50 feet from the surface, within which range must be made the correction we propose to apply. However, the correction is a small one, and over the territory occupied by the German stations it is known with more accuracy than elsewhere generally.

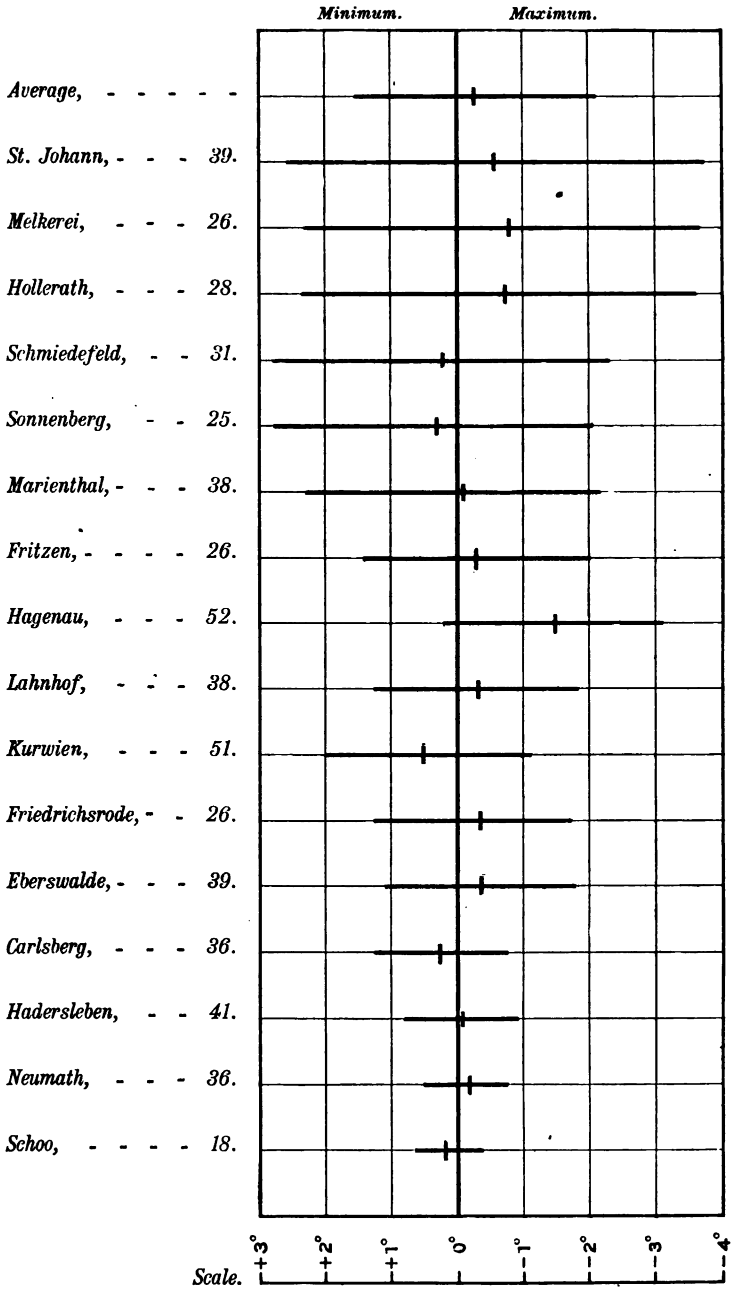


FIG. 23.—Forest temperature differences for the year at height of the tree top (*W—O*).

The correction which is used is that given by Mr. Ferrel in his "Recent Advances in Meteorology," and is taken from the column for "the Alps and Germany" in the table on page 180. In no place does this correction, as applied to the German tree-top observations, surpass 0°.11 F., (0.06°c) and it is always negative. After making this correction the observations will be treated as if the fictitious elevated stations were real and the values of *W′—O′* (here primed to distinguish from those at the level of 5 feet) will be discussed as were those of *W—O* in the preceding section.

Fig. 23 represents the mean annual values of *W′—O′* for maxima and for minima; the maxima always negative and below the zero line, the minima always positive and above. The names of stations are placed opposite the lines which belong to them, and for each station is given the elevation in feet above the surface of the ground. As in the preceding section, the length of the line indicates the reduction of range of temperature in the tree top, as compared with that outside at the same height, and the point in the middle of the line (marked by a short cross bar) indicates the reduction of mean temperatures.

This diagram presents the same features as the corresponding one for lower levels, but there is, if anything, more variation for the individual stations. Also, the mean temperature is here sometimes higher in the tree tops than over open fields. This is the case in five out of sixteen stations.

It is noteworthy that the reduction of the annual temperature in tree tops does not appreciably depend on the height of the station above the ground. The lowest (Schoo) shows the smallest reduction of temperatures. It should have the largest because nearest the ground. On the other hand, the highest station (Hagenau) stands about midway. The next highest (Kurwien) stands somewhat lower in the series, while one of the two next highest (St. Johann) leads the series. Nor does any feature (reduction of maxima, minima, or mean temperature) show any distinct distribution with reference to the height of the station.

Taking up the individual tree-top temperature diagrams we find them strongly resembling those for the observations at the 5-foot level, but with greater variation between the individual diagrams. That for Friedrichsrode (Fig. 24) is a fairly smooth and representative one, and it greatly resembles those of the preceding section. The minima are raised, the maxima lowered, the action is a cooling one, and it is most marked in summer. These features are all visible in the temperature diagrams at the 5-foot level. The cooling effect is, however, sometimes distributed through the year with some approach to evenness.

The reduction of the minima is often relatively great (Fig. 26, St. Johann). It is not rare that this is greater than the reduction of the maxima, leaving not a cooling, but a warming action on the part of the woods.

Tree-top temperature differences woods and open fields (W—O).

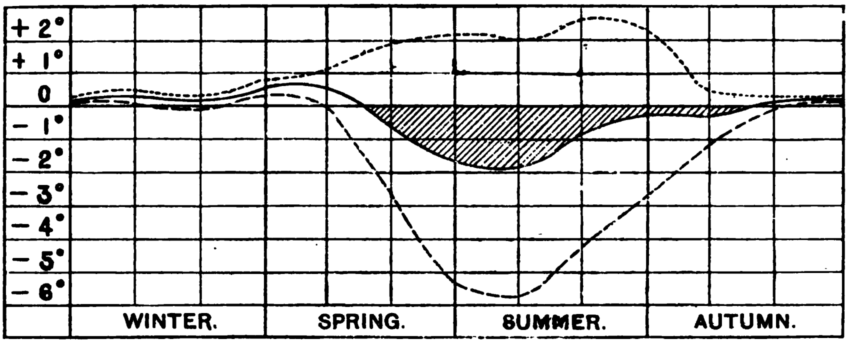


FIG. 24.—Friedrichsrode.

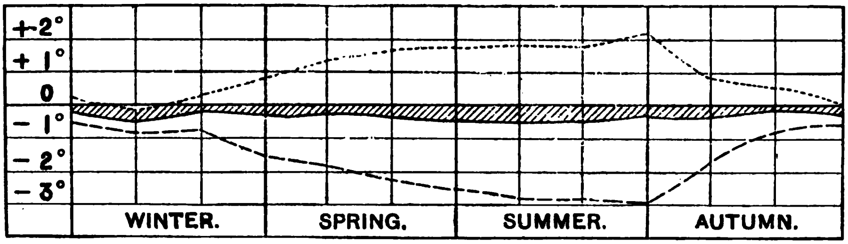


FIG. 25.—Eberswalde.

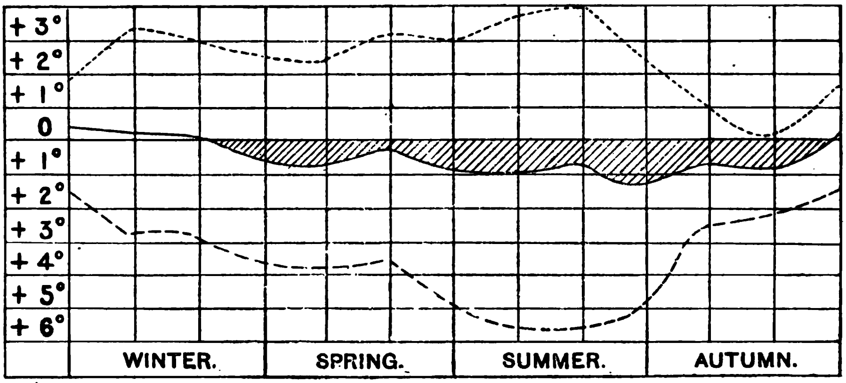


FIG. 26.—St. Johann.

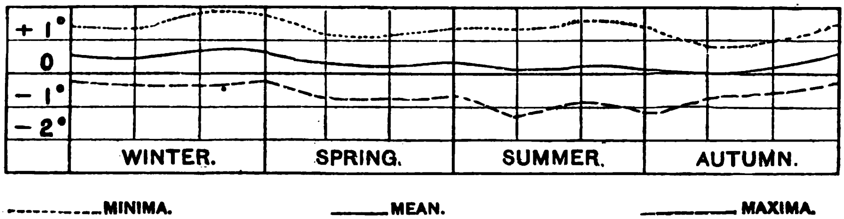


FIG. 27.—Carlsberg.

Tree-top differences (W—O).

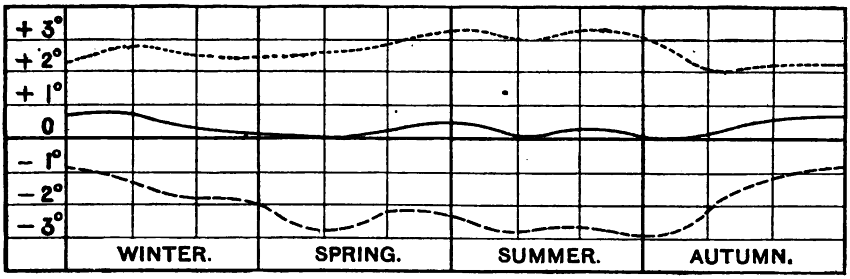


FIG. 28.—Sonnenberg.

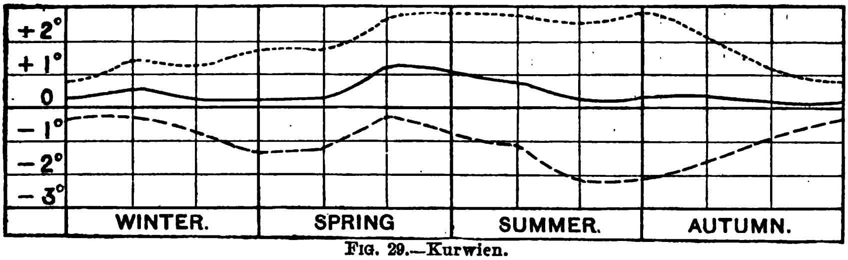


FIG. 29.—Kurwien.

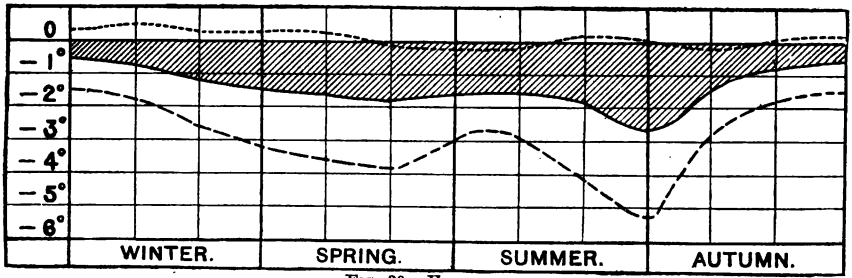


FIG. 30.—Hagenau.

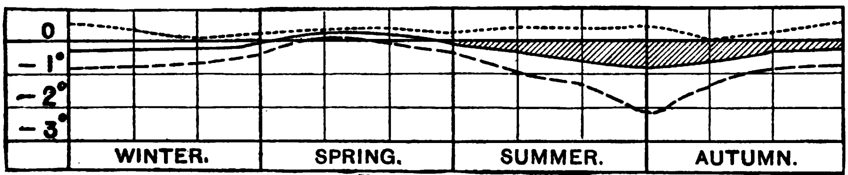


FIG. 31.—Schoo.

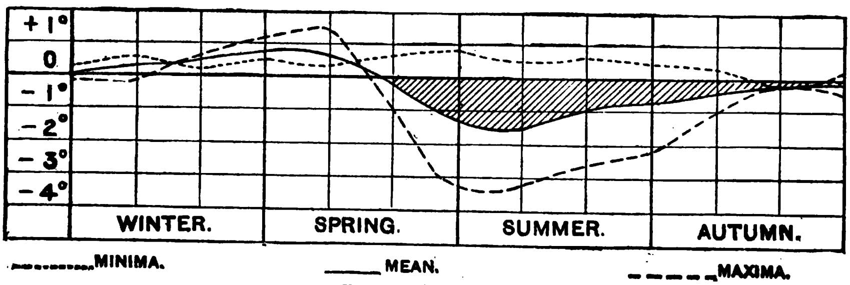


FIG. 32.—Neumath.

Fig. 30 is that for the station with the greatest elevation above the surface (Hagenau), and Fig. 31 that for the least (Schoo). They show great differences, but there is no connection between the diagrams through those for the intermediate stations. They are alike, and of especial interest, in that in both the reduction of the minima is only a small fraction of a degree. Fig. 32 (Neumath) gives the only case where the maxima were warmed decidedly more than the minima. This increases the range and makes the temperature more excessive in the late winter and early spring months.

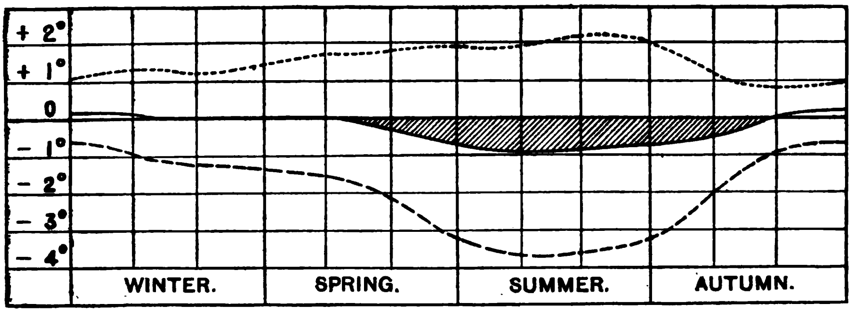


FIG. 33.—Average differences of tree-top temperature, sixteen German Stations ($W - O$).

The average differences of tree-top temperatures ($W'-O'$) are graphically given in Fig. 33. It is at once seen to be very similar to the corresponding Figure (17) for the elevation of 5 feet. There is the same elevation of minima, the same lowering of maxima, the same cooling effect, and the same exaggeration of all features in summer. The reduction of minima is, however, more nearly equal to that of the maxima,

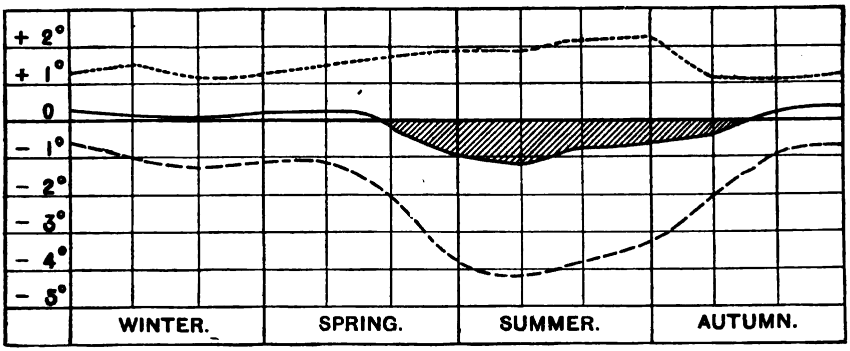


FIG. 34.—Tree-top temperature differences for four stations with average height of 24 feet.

and there is, consequently, less cooling. It seems, therefore, that the tree-top station is intermediate in temperatures between the base station and that in open fields.

It will be interesting to see if there is any difference through the year on account of elevation of the tree tops above the ground. To ascertain this the four lowest stations were taken (two in evergreens and two in deciduous trees) and their values of $W'-O'$ were combined. The result is Fig. 34. The average height was 24 feet. The four

highest (also equally divided between deciduous trees and evergreens) were similarly treated, with the result shown in Fig. 35. There appears no unmistakable difference between them due to anything but individual irregularities.

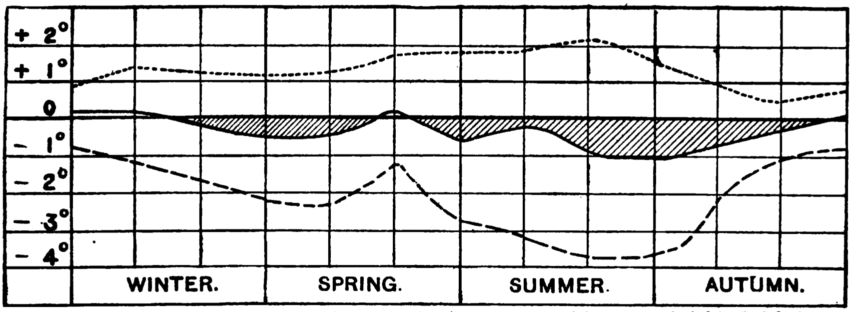


FIG. 35.—Tree-top temperature differences for four stations with average height of 46 feet.

The stations for deciduous trees and for evergreens were then aver-

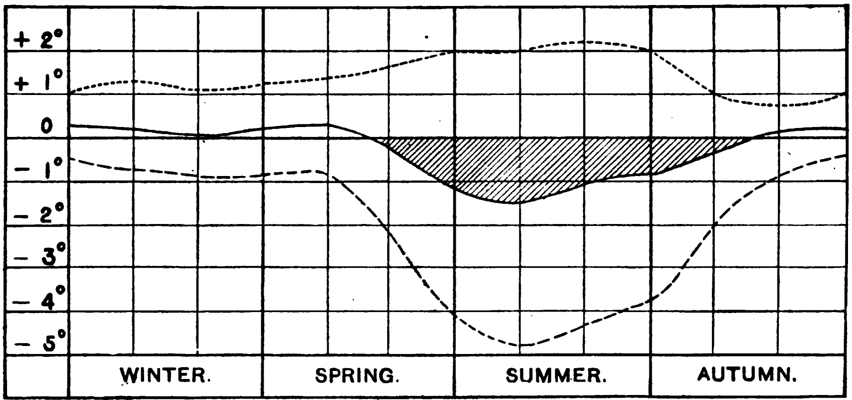
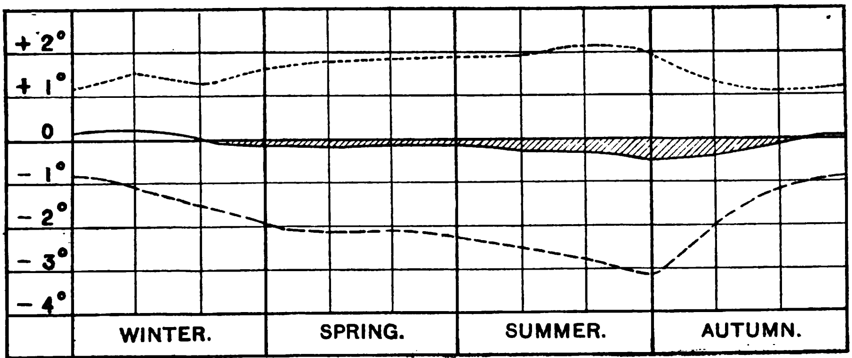


FIG. 36.—Tree-top temperature differences, German stations (*W — O*)—deciduous trees.

aged separately, as for the preceding stations. Fig. 36 is the diagram



— — — — *Deciduous trees.* - - - - - - - - - *Evergreen trees.* ——— *Average of all.*

FIG. 37.—Tree-top temperature differences, German stations (*W — O*)—evergreen trees.

for deciduous trees; Fig. 37 for the evergreens. The reductions for evergreen trees are less in quantity than for the deciduous, and are distributed more evenly through the year.

TEMPERATURE GRADIENTS.

So far the discussion has been as to change of temperature horizontally, or the horizontal temperature gradient. The tree-top observations permit also the study of the vertical distribution of temperatures, and this is a matter of considerable interest, because from it can be drawn some conclusions as to the stability of forest air; that is, as to its tendency to originate meteorological disturbances or to take part in those which approach it. This can be studied within the forest, because there are two stations—one above the other; but it can not, unfortunately, be studied outside the forest, as the station there, in the usual meteorological services, is single. In order to get around the difficulty that the stations are not at the same height, the gradients are expanded to the uniform height of 100 feet; that is, the vertical temperature gradients in the figure are those which would occur in forests if the temperature continued to change at the same rate through 100 feet (30.48 m.). The height of this assumed station is its height above the ground, decreased by 5 feet (1.5 m.) (the height of the lower station). As the irregularities in the vertical differences are exagger-

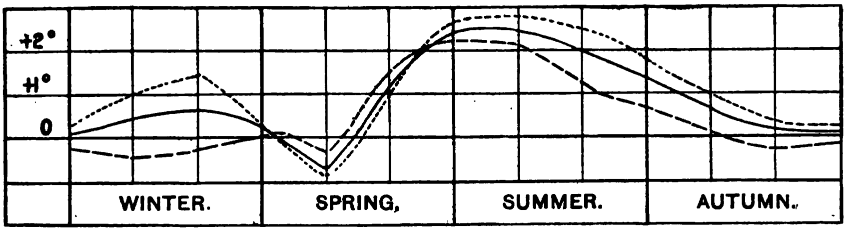


FIG. 38.—Vertical temperature, gradient in woods, degrees Fahrenheit for 100 feet.

ated in increasing them for 100 feet, only the data from the eight highest stations were used. These give a distance between lower and upper instrument of from 31 to 48 feet, averaging 38 feet (11.6 m.). Three of these stations were for evergreen trees (average distance 43 feet) (13 m.) and five deciduous (averaging 35.5 feet) (10.8 m.). These were arranged separately.

The results appear in Fig. 38. The unbroken line represents the gradients for the average of all eight stations, the broken line for the evergreens, and the dotted line for the deciduous trees. The vertical gradients are surprisingly large, when compared with the average. In no case would the latter be more than 0°.25, and it would always be negative. Here the gradients vary from 0°61 F. per 100 feet in April (for deciduous trees 0°.77, for evergreens 0°.35) to + 2°.50 in July (deciduous + 2°.62, evergreens + 2°.31). In summer the average gradient under trees is about + 2°; that is, it grows warmer as we ascend at the rate of two degrees per 100 feet (31 m.). Outside in the general average it grows colder by about a quarter of a degree. In early spring the

gradients are somewhat alike in and out of woods. In other parts of the year it generally grows warmer as one ascends.

A higher temperature of the air above than below is called a reversal of the vertical gradient, and it appears that in the woods this reversal occurs especially in summer. It also occurs in the open air regularly at night and often becomes very marked on a clear summer night, especially toward morning. The gradient is at such times generally three or four degrees and may, under exceptionally favorable circumstances, be several degrees more. The same thing is true throughout the day in the winter months, but the gradient is then not generally large. The action of the forest, therefore, tends to produce a vertical distribution of temperature like that over snow, or over level fields on clear summer nights. It should be noted that this arrangement is in favor of stability of the air. The warmer air is the lighter and is on top. Still this tree-top air is, in the warm season, usually cooler, and consequently heavier than the air at the same level outside, as is shown by Fig. 38. This is true of the entire column of forest air—that is, air in the forest—and this heavier air will tend to flow out.

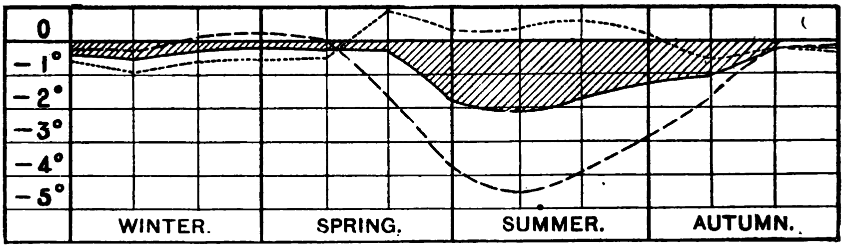


FIG. 39.—Forest temperature, differences at Halatte, under deciduous trees.

TEMPERATURE ABOVE FORESTS.

Systematic observations above forests have been seldom taken. Among them are those taken by M. Fautrat a few miles north of Paris, in the forests of Halatte and Ermenonville. In the first the observations were under and over deciduous trees, oaks, and hornbeams, in the second over pines. The soil at the latter place was a coarse quartz sand, and the open field station was over a sandy plain. The surface observations were taken at a height of 1.4 meters (4 feet 7 inches), while those above trees were 14 meters (46 feet). The instruments appear to have been close to the top of the pines, but many feet above the deciduous trees. The published observations are somewhat fragmentary, from two to four years being available. The temperature diagrams near the ground are given in Figs. 39 and 40. The first is for the deciduous forest and is of the familiar type. Fig. 40 exhibits some striking peculiarities, chiefly in the exaggeration of the minima and

the constantly cooling mean temperature. These features may be in part due to the soil. Otherwise the diagram resembles the corresponding one of the preceding section. Fig. 41 gives the two forest tem-

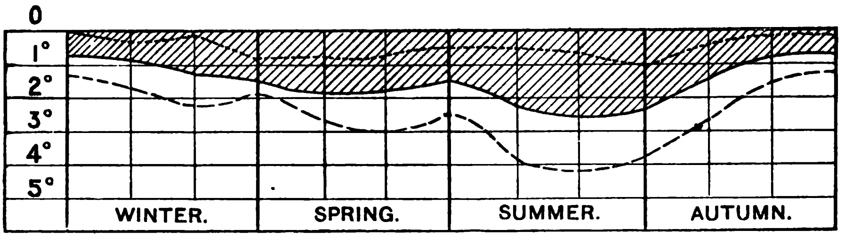


FIG. 40.—Forest temperature, differences at Ermenonville, under pines. Soil: coarse, bare sand.

perature diagrams above trees from M. Fautrat's observations. The line for mean temperature is omitted because of the narrowness of the space. It would, in each case, hug the zero line. It is interesting to

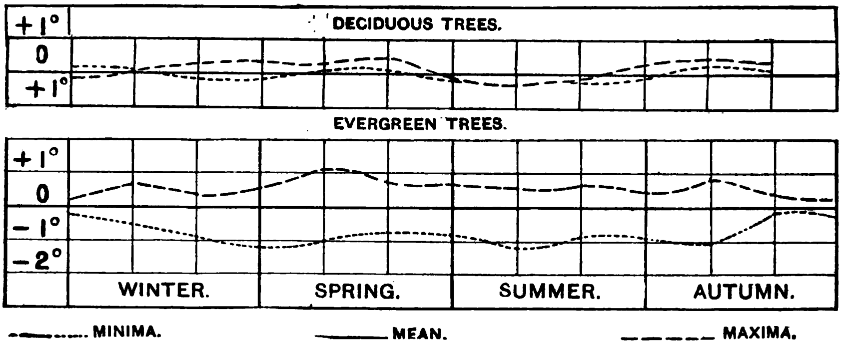


FIG. 41.—Forest temperature, differences above trees—from Fautrat's observations.

note how the temperature diagram, in Fig. 41, has here contracted. That for evergreen trees, with the instruments close to the tops, is very narrow, while that for deciduous trees, instrument about 20 feet above

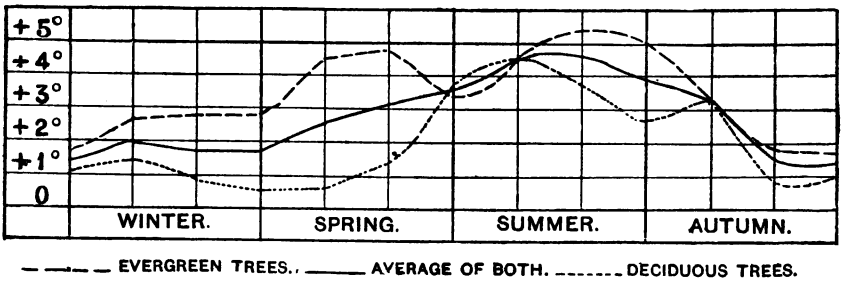


FIG. 42.—Vertical temperature gradients from observations above trees.

the tops, has contracted so as to vanish at times. It is evident that if the instruments had been put a few feet higher up it would have entirely disappeared. Fig. 42 represents the vertical gradients from M.

Fautrat's observations. They are all reversed throughout the season, and the summer gradients are about +4°. Those over evergreens are greater than those above the deciduous trees, or, perhaps more properly, the gradients decrease as we ascend above the top of the deciduous trees.

The observations under the direction of Dr. Lorenz-Liburnau at Ried were taken in the warmer months of 1888. They have been published quite recently (1890), and came under the eye of the writer only after the preceding part had been finished. They were not systematically taken, but only at such times as seemed especially suited for the study of especial features, and hence they throw light on some points which the systematic observations do not sufficiently care for. One of these is the change in temperature above and below the crown of foliage for the same station and time. Dr. Liburnau gives the following mean results from many individual observations. The plus sign indicates an increase of temperature upward, the minus a decrease.

	Change—			
	From 16.4 to 36.1 feet.		From 36.1 to 50.8 feet.	
	°*F.*	°*C.*	°*F.*	°*C.*
Morning hours	+1.08	.60	+3.24	1.80
About noon	+1.57	.87	+2.43	1.35
Afternoon	+1.40	.77	+2.16	1.20
Early night	+ .18	.10	− .11	.06
Late night and early morning	− .63	.35	− .27	.15

The station at 36.1 feet was in the crown, that at 50.8 feet above it. The distances are not great enough to get good values for the vertical gradients, but it is evident that these are very large, and greater above the crown than below.

These observations were all taken with a clear sky and calm air. Some interesting figures are also given for the differences between field and forest temperatures when the air is still and when it is in motion.

The following table gives the values of $W-O$ under these circumstances:

	Under trees, 16.4 feet. (5 m.)		Tree crown, 36.1 feet. (11 m.)		Above trees, 50.08 feet. (15.5 m.)	
	°*F.*	°*C.*	°*F.*	°*C.*	°*F.*	°*C.*
Morning hours:						
Calm	−2.11	1.17	−1.53	.84	+2.16	1.20
Windy	−1.24	.70	+1.07	.04	+2.29	1.27
About noon:						
Calm	−2.47	1.37	− .54	.30	+2.29	1.27
Windy	−1.62	.90	+ .02	.01	+2.54	1.41
Windy	−2.02	1.12	−1.13	.63	+1.30	.72
Afternoon:						
Calm	−1.37	.76	− .54	.30	+1.03	.57
Windy	−1.19	.66	−1.12	.62	−1.28	.71
First and last night hours (calm)	−2.56	1.42	−3.06	1.70	−3.19	1.77

Under the crowns the temperature is lower in the forest, but above the crowns it is usually higher. The wind reduces the difference under and in the crowns, but makes little difference above them.

Putting the preceding results together, it appears that the forests reverse the vertical gradient, and that the gradient grows larger as the surface of the forest is approached. Toward the ground the change is slow; upward it is very rapid, so rapid that the special cooling effect of the forest must disappear at no great height. The surface of the surface of the forest is, meteorologically, much like the surface of the meadow or cornfield. The isothermal surface above it in sunshine is a surface of maximum temperature, as is the surface of the meadow or cornfield. From this surface the temperature decreases in both directions.

TREE TEMPERATURES.

The disturbances of temperature under trees, so far discussed, would be the same in kind if the surface covering called a forest were inorganic. They are due to the screen formed by the forest against the sun's rays and against the radiation from the soil to the sky. The kind of effect would be the same if the forest were dead, but the quantity might be quite different. The shade under a dead tree is much less than under a live one. This is due to a considerable extent to the fact that its leaves are no longer spread across the path of the sun's rays, and the heat of the latter is not so much absorbed by the evaporation of water. These, again, may be purely mechanical effects, and it is still left uncertain whether the living tree affects the temperature through its vital action; whether in the processes of life the tree does not abstract enough heat from the air, or add enough heat to the air, to be meteorologically sensible. There is abundant reason to think that it may exert such action, because all vital processes result in the absorption or radiation of heat—and so do purely inorganic chemical processes. The tree, as an organic being, is a source as well as an absorbent of heat; the only question is whether the heat it absorbs or emits is enough in quantity to make a sensible difference in the temperature of the air. The analogy of the hot-blooded animal leads one to look first to the tree itself for a solution of this question. Even the cold-blooded animal, when of a large size, has its own temperature slightly higher than the mean temperature of the medium in which it lives. The tree is a living body. Is the same true of it?

The most elaborate series of observations of tree temperatures are those taken at Geneva for the five years, 1796 to 1800. The thermometer was introduced into the trunk of a horse-chestnut tree to the depth of 6 inches, or about half of the way to the heart. The temperatures were read three times daily (sunrise, 2 p. m., and sunset), and observations were also taken at the same hours in the air and at several depths

in the soil. In Fig. 43 is given a graphical representation of the mean monthly temperature, for the tree (unbroken line), for the air (broken line), and for the soil at the depth of 4¼ feet (dotted line) The straight lines across the diagram horizontally represent the mean annual temperatures for these three positions respectively. It appears that the mean temperature of the tree is lower than that of the air (by 0°.3), and still more so than that of the soil at the depth of 4 feet (by —1°.7).

The results are not easy to interpret. A part of the difference is probably due to a retardation of diurnal maxima and minima in the tree. M. Becquerel found this retardation very marked, but his observations were of such a kind that they can not be satisfactorily tabulated. He found that in small branches the summer diurnal maximum was retarded by two or three hours, while for larger ones it might be

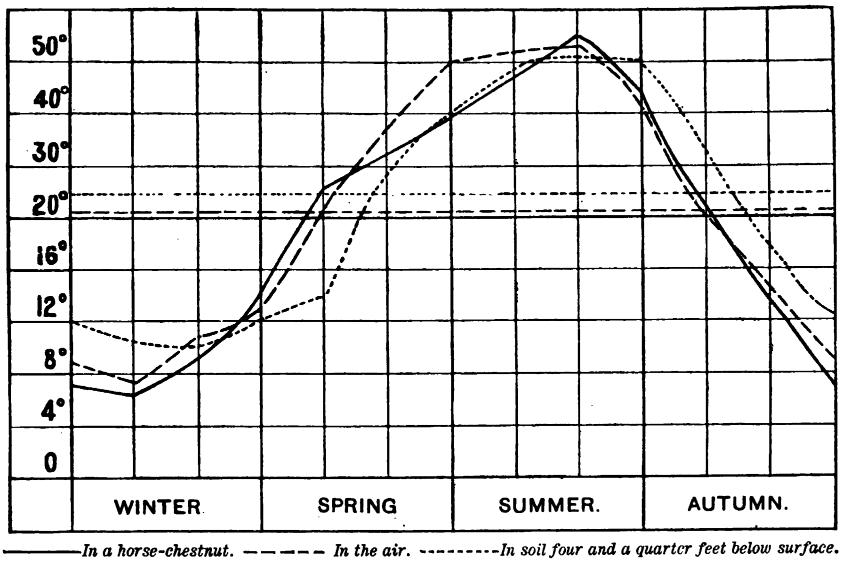


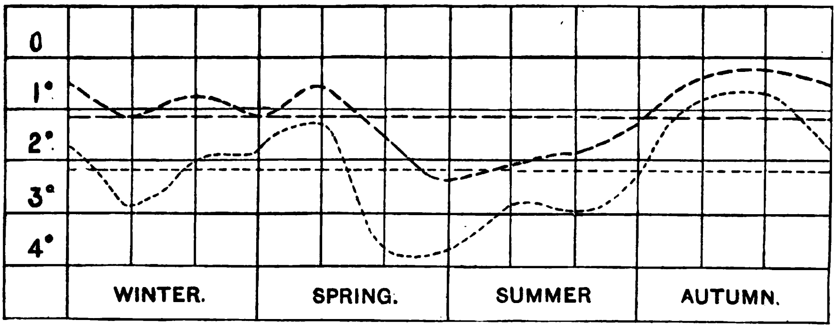
FIG. 43.—Tree temperature—Geneva observations.

twice this. This being the case, the daily observations would not fall at the same parts of the daily curve of temperature, and whether the correction to be applied to bring them to a comparative condition should be positive, negative, or zero would depend on the hours used and on the retardation in the tree. The differences shown in Fig. 43 are, therefore, not necessarily the true differences, and with the proper corrections many of the irregularities of the curve would probably disappear. The curve, however, indicates that the tree is relatively warmer in early spring and late summer and the opposite between these dates, and also that the summer maximum is retarded as compared with that of the air.

The trunk of the tree is so constructed as to be a very poor conduc-

tor of heat. The wood itself is a bad conductor; the tissue is filled with air or sap, both bad conductors; and it is protected by a layer of bark which is an especially poor conductor. All these would tend to prevent the access of heat to the interior of the tree and to prevent its exit when there.

These conditions would explain the retardation of the maximum in trees but would not explain the lower mean temperature nor relatively low temperature of winter. Some light may be thrown on their condition by the values of the differences of temperature between tree and air surrounding it (*T*—*W*). These observations were not made in the German service but were in the Bavarian. It is necessary, therefore, to depend here on the much shorter series of published observations of the latter service. Observations of the temperature of the tree were taken at the base and in the crown. The thermometer was always introduced to the heart. For the stations at the base this distance varied from 4 inches to 11.2 inches averaging 6.3 Paris inches



——— *In tree crown. Average depth 4.3 inches.* - - - - - *In tree base. Average depth 6.3 inches.*

FIG. 44.—Temperature differences between tree and air.

(170 mm.). The observations in the crown were made at an average height of 31.4 feet (varying from 20 to 46). The depth of the thermometers varied from 2.7 inches (73 mm.), to 8.5 inches (230 mm.), averaging 4.3 Paris inches (116 mm.). The number of trees on which observations were made through the year was eight—five evergreen, and three deciduous. The results are represented in Fig. 44, the broken line showing the tree-crown observations, and the dotted line those near the base. The straight lines, parallel to the zero line, represent the corresponding mean values. While in Fig. 43 the mean temperatures are used, in Fig. 44 the monthly values of *T*—*W* are shown.

In the arrangement of each one of the curved lines in Fig. 44 about its mean value, the corresponding straight line, there is nothing but what might be expected in observations in the interior of any inorganic mass, such as a rock, a mass of masonry, or a dead tree. In fact, except for certain irregularities which are probably due to the shortness of the series of observations, the curves are much like the value of

$W-O$ for soil temperatures. The tree, like the soil, is warmer in winter and cooler in summer than the mean value for $W-O$. It is also noteworthy that for the smaller trunks and branches the variations from air temperature, and the variations from its own mean, are smaller, exactly as would be the case with any inorganic body.

In short, the variations of temperatures correspond to the variations of temperature in inorganic bodies of similar character and similarly placed. In fact, Bravais, in winter observations at Bossekop, Lapland, found the temperatures in a live and dead tree to be practically the same.

It only remains to discuss the average lower temperature in trees. In Dr. Ebermayer's tables, this reduction of temperature at the base of trees as compared with air is 2°.2, while at the crown, with an average diameter of limb two-thirds as great, it was 1°.2. This reduction may be due to the temperatures of the water taken from the ground.

When the sap flows most freely—in spring and early summer—the soil is cooler than the air and the water drawn from the soil must have its temperature. The tree is so thoroughly protected from the conduction of heat that this temperature must change but slowly as the sap rises. It must give a lower temperature to the interior of the tree and this lowers the annual mean. At the same time, for reasons to be given in the next section, the return sap is probably also cooled to some degree, so that all the water circulating in the tree is, in the warm season at least, cooler than the air.

The foliage seems especially arranged for the exchange of heat. Its surface is very large for its mass, and it is so exposed to the open air, to the sky, and to the sun's rays that it is adapted to receive and part with heat easily and quickly. The temperature of leaves considered as purely inorganic bodies should, therefore, be lower than that of the air at minimum, and higher at maximum. There seem to be no systematic observations on the temperatures of foliage, but botanists have taken a good many occasional observations which confirm the statement just made. The temperature of the leaves falls decidedly lower than that of the air on clear summer nights, the difference being generally several degrees and sometimes reaching eight or ten. On the other hand this temperature rises in the sunshine to several, and occasionally to many degrees of temperature higher than the air around; in other words the maximum temperature of leaves in sunshine is higher than that of the air, while the minimum temperature in clear nights is lower than that of the air. A leafy branch with the cut end in water and exposed to the sunshine has been found to be cooler than one not in water, suggesting that the average temperature of foliage is on the whole lower than that of the air about it.

VEGETATION AND AIR TEMPERATURES.

It appears from the preceding section that the tree shows, of itself by its own action, no sign of warming the air and but little sign of cooling it. Systematic observations show this to be true of the framework of the tree, but no observations have been taken for the foliage and other exterior parts—the parts where most of the vital activity of the tree takes place. The great volume of chemical and physical changes which are produced here and which result in the growth of the tree and the formation of its fruits make it an open question (not yet decided by direct observations, which are not easily instituted) whether the tree does not affect temperatures sensibly. So far as any observations go—those in the tree-crown for instance—they show little clear evidence of such a meteorological effect, but it will be of interest to see what can be concluded theoretically. The changes which take place at the leaf-surface, due to vital activity, are produced by the trees in common with the other and lower forms of vegetation and consequently the problem to be solved is double, namely: Do the vital processes of vegetation, in which heat is utilized or given off, produce a sensible effect on air temperatures, and is the effect, if any, different for trees and for meadows, mixed growths, or crops?

Vegetation has a complicated relation to heat in the various organic processes. In the transpiration of water it utilizes large quantities of heat, changing it from that sensible in temperature to the work of sustaining the water in a condition of vapor. This latent heat becomes again sensible when the water is condensed, but this may occur at a distance from the place where the water is taken up. By unlocking the combination of carbon and oxygen in carbonic acid, using the carbon and rejecting the oxygen, it reverses the action of combustion and so takes up heat. On the other hand, in the various processes in which oxygen is combined, it performs a process analogous to combustion and gives out heat. This process is sometimes so active (as in the germination of some seeds and the flowering of some plants) that the temperature of the parts is raised several degrees above that of the outside air, and it is sensibly warm to the hand. There are other more complicated processes going on in the plant, the relations of which to heat can not be foretold.

The quantity of heat used in these processes varies greatly with the season, the temperature, the condition of the plant, and so on. It can be ascertained only approximately even in the processes best understood. Yet the problem has so many features of interest that even such an approximate solution is desirable. For instance, the German forester Ney has attempted to show that the unseasonable frosts of mid-May in central Europe are due to the amounts of heat absorbed by plants at that season.

The transpiration of water by the plant is a vital process which needs the stimulus of the sun's rays; it takes place in the green parts

only, and is especially active when these parts are young. It is the process by which the plant gets rid of the surplus water after having drawn it from the soil in order to extract from it the nutriment which is present in only a very highly attenuated solution. Botanists have made many measurements of its amount and their results are extremely varied, due partly to the fact that this function varies much naturally, and still more perhaps to the fact that the experiments are generally made under conditions which are not natural to the plant. Sachs says that it is no rarity for a tolerably vigorous tobacco plant at the time of flowering, or a sun flower of the height of a man, or a gourd plant with from fifteen to twenty large leaves, to transpire from one to two pints of water on a warm July day; and, so far as may be judged by the use of branches with the cut end in water, it may be believed that large fruit trees, oaks or poplars absorb, transport through their stems, and transpire from the leaves, ten to twenty or more gallons of water daily. He also quotes Haberlandt to show that the amount transpired by a stalk of Indian corn, in its season of 173 days, is 3 gallons; by a stalk of hemp, in 140 days, is 6 gallons; by a sun flower plant, in 140 days, is 14½ gallons.

It is not generally practicable to compare the transpiration with known meteorological phenomena, such as evaporation from a water surface, or from the soil, or the precipitation, but some such comparisons have been made. For instance, comparing the leaf surface to an equivalent water surface, Unger makes transportation from the former 0.33 of the evaporation from the latter; Sachs for white poplar 0.36, for the sun flower 0.42. Comparisons have also been made between the transpiration from plants and the evaporation from the surface over which the plants stand. Schleiden thought that the transpiration from the forest was three times that of a water surface equal to the territory covered by the forest. Schübler thought it only a quarter; and Pfaff, who studied a solitary oak in a garden, found that it varied from 0.87 to 1.58. Comparing the transpiration of plants with the evaporation from the bare soil which would be covered by them, Hartig thought the transpiration of a forest less, Schübler found it 0.6 for the forest and 3.0 to 5.0 for sod. Marié-Davy found it, for firs 1.18, for beeches 1.32, for sod 1.86. As to the influence of sunlight, Vines quotes from Wiesner, who carried on his observations with special precautions to prevent influence from other stimuli of the transpiration. The results are given in the following small table, in which the evaporation in full sunlight is taken as unity.

Plant.	Transpiration in sun.	In diffused daylight.	In darkness.
The common broom	1.00	0.40	0.37
Lily (*L. croceum*)	1.00	0.52	0.33
Bushy mallow	1.00	0.40	0.33
Indian corn	1.00	0.12	0.15
Means	1.00	0.36	0.27

From this it appears that it is the direct sun's rays that most promote transpiration. When in diffused light the plant transpires only a third as much, and in darkness only a quarter. The application of this to forests is evident, because there at any time of day a considerable part of the foliage is in shade.

The estimates of transpiration are very numerous and it is not easy to get from them an estimate of the amount for plants in terms of evaporation or precipitation. In the following table those have been selected which were most easily expressed in terms of quantities observed meteorologically. The duration of the active season was taken into account in each case.

Observer.	Plant.	Transpiration expressed as rainfall equivalent in inches. Daily.		Annual.		Authority.
		Inches.	*Mm.*	*Inches.*	*Mm*	
Hales	Sunflower	0.13	3.30	15.2	381	Ebermayer.
Hales	Cabbage	0.12	3.05	14.4	366	Do.
Hales	Grapevine	0.03	.76	4	101	Do.
Hales	Hop	0.05	1.27	5.6	142	Do.
Schleiden	Clover & oats	0.11	2.79	13.6	345	Do.
Vogel	4 years beeches	0.003	.076	0.43	11	Do.
Vogel	4 years firs	0.002	.051	0.28	7	Do.
Vogel	Wheat field	0.62	15.75	4.4	112	Do.
Vogel	Barley field	0.56	14.22	3.9	99	Do.
Hartig	24 years mixed forest	0.021	.533	3.8	96.5	Do.
Pfaff	Oak	0.21	5.33	193.2 (?)		Austrian Met. Journal.
Höhnel	115 years beeches	0.05	1.27	9.2	233	Sachs.
Schübler	Low spear grass	0.08	2.03	14	355	Duchartre.
Haberlandt	Oats	0.13	3.30	9.1	231	Do.
Haberlandt	Barley	0.07	1.78	4.9	124	Do.

The best that can be done with these very variable measures is probably to take a mean of the values of Hartig and Höhnel. This gives the transpiration of the forest as 6.5 inches (165 m.) for central Europe, or about one quarter of the precipitation. That this is not much too large is indicated by Pfaff's* results, which appear to be excessive, and that it is not much too small is indicated by those of Vogel.

The most elaborate investigations on transpiration of forest trees were made by F. B. Höhnel, and since a discussion of these appears in the report of the chief of the forestry division (Mr. B. E. Fernow) for 1889, I quote his language on this subject:

The quantity of water so used is as variable as the amount of precipitation and in fact within certain limits depends largely upon it. That is to say, a plant will transpire in proportion to the amount of water which is at its disposal. Transpiration is also dependent on the stage of development of the plant, on the nature of its leaves and amount of its foliage, on temperature, humidity, and circulation of the air, on intensity of the sunlight, and on temperature and structure of the soil and on other meteorological conditions. Rain and dew reduce transpiration, wind increases it. The amount of transpiration depends considerably upon the thickness of the leaves, therefore the surface of the foliage is not a reliable measure, but it should be compared with the weight.

With so many factors to vary them the values which may be given for the amount of transpiration of various kinds of trees can only be approximations of its range

within wide limits. All the figures which have been published, based upon calculations or experiments in the laboratory, are useless for practical purposes. Especially do those figures which represent the requirement of the plant as exceeding the amount of precipitations, exhibit on simple reflection, their absurdity.

If the requirement per acre is considered, the density of the growth of plants must also be taken into account.

The first careful and comprehensive investigations into the water requirements of forest trees were made by the Austrian forest experiment stations in 1878 (F. B. Höhnel), and full tables of the results obtained can be found in the records of those stations.

An average of the many figures there presented would make the amount of transpiration per 100 grams of dry weight of leaves in conifers 4,778 to 4,990 grams of water, in deciduous-leaved trees 44,472 to 49,553 grams of water. That is to say, the deciduous trees transpired about ten times as much as the conifers, and comparing the two extremes of transpiration, the deciduous tree with the highest rate of transpiration utilized twenty three times more water than the coniferous tree with the lowest rate. Ash, birch, and linden were found to be the most vigorous transpirers, oaks and maples transpiring much less. Curiously enough, while in the conifers shade reduced the transpiration considerably, in the deciduous trees it had the opposite effect.

During the period of vegetation the following varieties transpired per pound dry weight of leaves:

	Pounds of water.
Birch and Linden	600–700
Ash	500–600
Beech	450–500
Maple	400–450
Oaks	200–300
Spruce and Scotch Pine	50–70
Fir	30–40
Black Pine	30-40

The next season, which was more favorable to transpiration, the amounts were larger; the deciduous trees transpiring from 500 to 1,000, the coniferous from 75 to 200 pounds, or in the proportion of one to six.

The following actual amounts transpired per 100 grams of dry leaves during the third season (1880), will show the relative position of the various species (European):

	Kilograms.		Kilograms.
Ash	101, 850	Scotch Pine	12, 105
Birch	91, 800	Fir	9, 380
Beech	91, 380	Austrian Pine	7, 005
Hornbeam	87, 170	Aspen	95, 970
Elm	82, 280	Alder	93, 300
Maple (*A. campestre*)	70, 380	Linden	88, 340
Norway Maple (*A. platanoides*)	61, 180	Larch	125, 600
Oak (*Q. robur*)	69, 150	Average deciduous trees	82, 520
Oak (*Q. Cerris*)	49, 220	Average conifers	11, 307
Norway Spruce	14, 020		

The variability of transpiration from day to day is of wide range; a birch standing in the open and found to have 200,000 leaves was calculated to have transpired on hot summer days 700 to 900 pounds, while on other days its exhalations were probably not more than 18 to 20 pounds.

A fifty to sixty year old beech was found to have 35,000 leaves, with a dry weight of 9.86 pounds; a transpiration at the rate of 400 pounds per pound during the period of vegetation would make the total transpiration 3,944 pounds per tree (about 22 pounds daily); and since 500 such trees may stand on 1 acre, the transpiration per

acre would amount to 1,972,000 pounds, while the precipitation during the same period would be 2,700,000 pounds.

The transpiration of a thirty-five-year-old beech with thinner leaves, of which there were 3,000, with a dry weight of 0.79 pounds, would under the same conditions transpire 470 pounds per 1 pound of foliage, or 373 pounds per tree (about 2¼ pounds per day from June to November); and since about 1,600 such might be found on an acre, the total transpiration might amount to 596,800 pounds per acre, or considerably less than the amount of rain-fall.

Calculated for summer months during June, July, and August alone, the requirement of the two beech growths was 20,000 and 5,000 pounds per day an acre respectively. Conifers, as was stated, transpire one-sixth to one-tenth of the amount which is needed by deciduous trees.

The amounts transpired by agricultural crops and other low vegetation, weeds, etc., have been found to be considerably larger, as will be seen from the results of the latest investigations by Wollny, which I have calculated per acre to make them comparable with the foregoing results:

Agricultural crops.	Time of vegetation.	Water consumption per acre.
		Pounds.
Winter rye	Apr. 20–Aug. 3, 1879	2,590,186
Barley	do	2,720,238
Peas	do	3,144,128
Red clover (first season)	Apr. 20–Oct. 1, 1879	3,070,012
Summer rye	Apr. 20–Aug. 14, 1880	3,000,486
Oats	Apr. 20–Sept. 14, 1880	3,422,584
Beans	Apr. 20–Sept. 10, 1880	3,139,233
Red clover (second season)	Apr. 20–Oct. 1, 1880	4,109,198

I repeat again that these figures can only be very rough approximations denoting maxima of transpiration, and that the amounts transpired per acre depend largely on the amounts furnished by precipitation. Therefore our forest areas within the arid region of the country probably transpire a minimum of water, their scattered growth and their coniferous composition, with the scanty rain-fall, reducing the amounts to lowest limit.

Taking a rain-fall of 20 inches, which represents say 4,500,000 pounds of water per acre, a coniferous forest, assumed to transpire one-sixth of the amount found for the older beech-forest under most favorable conditions of precipitation, would require hardly more than 330,000 pounds (presuming the same weight of foliage), or not 8 per cent of the total precipitation. To be sure, this amount must be available during the period of vegetation.

THEORETICAL CALCULATION OF HEAT ABSORPTION.*

There is another way in which the average amount of transpiration can be approximated, perhaps more closely than by the method of direct measurement. The water transpired comes mostly, if not entirely, from the soil. On evaporating it leaves behind it the matters held in solution, a portion of which is inorganic and is that which constitutes the ash of the plant. Assuming that the absorption by the plant is not sensibly selective in the average from a large number of individuals, then a knowledge of the annual addition of inorganic material, *i. e.*, ash, to the

* The computations in this section are made on the decimal system because of its greater simplicity.

forest, and the amount of mineral matter held in solution by the ground-water will enable us to compute the amount of water which has been evaporated. The required data, particularly the latter, are often known with some exactness. Takihg, with Grandeau, the average amount of of ash in the plapt at 5 per cent and the quantity of mineral matter in solution as two parts in ten thousand, the plant must transpire five thousand times the weight of its ash or two hundred and fifty times its own direct weight. Grandeau gives 6,497 kilograms as the annual production of a beech forest (wood and foliage), 6,442 as that of Norway spruce, and 6,420 as that of pines, for every hectare covered. These numbers multiplied by 250 would give the quantity of water transpired, which, reduced to thickness of the sheet of water over a hectare, gives the depth or rainfall equivalent. In these cases it gives 6.4, 6.3, and 6.3 inches, respectively. The numbers given by Grandeau are for central Europe, as were the preceding. The results by the two methods are 6.5 and 6.3 inches, which, by chance, are remarkably close to each other. Knowing the amount of water transpired, and the temperature at which transpiration takes place, it is easy to get the amount of heat used up in the process. The evaporation of any given weight of water would heat by 1° C. a weight of air which is $\frac{606.5 - 0.695t}{0.2375}$ times as great, where t is the centigrade temperature of the water evaporated. As water is 773 times as dense as air at the standard temperature (32° F.) and standard pressure (30 inches), the evaporation of a layer of water an inch thick takes up as much heat as would warm by 1° C. a layer of air of standard density and of a thickness of $\frac{606.5 - 0.695\,t}{0.2375} \times 773 =$ $(606.5 - 0.695t)\,3255$ inches. For different temperatures the thickness of the layer of a homogeneous atmosphere which might be cooled 1 degree for each inch of the layer of water evaporated is as follows:

Temperature.		Thickness of air layer.
°C.	°F.	*Miles.*
0	32	31.1
10	50	30.8
20	68	30.4

The cooling equivalent to the annual forest growth, is therefore about 6.4 times that expressed in this table and takes place through the entire season, but is greatest in late spring in sunshine, least in darkness in late summer. It acts, however, continually, and when the enormous thickness of the air layer is divided by 150 days (about the length of the active season) and this by the number of seconds in a day, the result per second does not appear so very large. As a convenient general expression it may be said that the evaporation of any depth of water would take up enough heat to cool by one degree (Fahrenheit in

this case) one million times that depth or volume of air, the latter being of average temperature and density.

In calculating the effect of the breaking up of the carbonic acid, we may assume that as much heat is used as would be given out by burning the same quantity of carbon in oxygen—that is, by remaking the compound. Grandeau gives as the annual product of carbon by plants, per hectare, 3,000 kilograms for forests, 1,500 to 4,500 kilograms for open fields, and, exceptionally, 15,000 kilograms for a field of giant maize. This is probably all derived from the carbon dioxide of the air. The burning of a kilogram of carbon produces 7,900 large calories of heat according to Andrews, or 8,080 according to Favre and Silbermann.

The large calorie is the amount of heat necesssry to raise one kilogram of water 1° C. in temperature; it would warm to the same amount $1 \div 0.237 = 4.22$ kilograms, or $4.22 \times 773.3 = 3263.3$ liters of standard air. The burning of the annual carbon productions above given would warm by 1° C. the thickness of air mentioned in the following table, in which 7,900 is used as the number of calories produced by the combustion of 1 kilogram of carbon:

	Calories used per annum per hectare.	Liters of air cooled.	Thickness of air cooled.
			Miles.
Forest	23.7×10^6	77.2×10^9	5.0
Prairie	11.8×10^6	38.6×10^9	2.5
	35.5×10^6	115.8×10^9	7.5
Maize	118.5×10^6	386.0×10^9	25.0

It appears that the heat absorbed by the entire carbon assimilation for a forest is only from one-fifth to one-sixth of that used in evaporating a layer of water an inch deep. As the latter is only a sixth or a seventh of the transpiration, it appears that the cooling which would be caused by the breaking up of carbonic acid, in order to form forest growth, is only from one-thirtieth to one-fortieth of that caused by the transpiration.

It is highly probable that the heat used in the former process is more or less closely made up by the heat produced in the oxidations that go on in the plant. In any case the cooling due to this source may be disregarded and only that of the transpiration be considered. It is estimated that the sun's rays, when the sun is vertical, pour out twenty-five calories per minute over each square meter of surface exposed vertically to it. Of this about 30 per cent is absorbed in passing through the atmosphere, when the sun is vertical and the sky clear, and very much more under other circumstances. The 17.5 calories, for a clear day and vertical sun, would in a single minute evaporate a layer of water 0.0011 inch thick. But the transpiration is about 6.5 inches for the season of about 150 days, or 0.00003 per minute. Thus the

sun's rays under these favorable circumstances pour on the surface $\frac{110}{3}$ times as much heat as is required for evaporation. If the maximum heat of sunshine is reduced by one-half for latitude, by seven-eighths because of night and of low morning and afternoon temperatures, and again by one-half because of cloudy weather, making its average value one-thirty-second that given above, yet there is more than enough over each square foot of forest to effect the transpiration.

It is only where the transpiration has been very active during the day and continues into the night that its cooling could be possibly injurious, but as the temperature cools the transpiration itself is checked, and besides the moisture which it has poured into the atmosphere serves as a screen to prevent rapid radiation from the soil, and its condensation returns some of the heat that had been taken up. There might, however, occur a combination of circumstances, very rapid transpiration during the day absorbing the sun's heat, a clear night, calm air and a low temperature from other sources coming on with the evening, when the transpiration might cause the temperature to fall below freezing. This could hardly happen, however, without a meteorological change toward cold, and this change must come on toward evening, for otherwise it would itself check the transpiration.

The combination would be more likely to occur over herbaceous growths, especially over grass and cereal crops, than over forests. Their transpiration, it appears from the table (page —), is decidedly greater than that of the forests, and they make rapid advances much earlier in the spring when such low temperatures are otherwise possible.

TEMPERATURES IN WOODS, GLADES, AND PLAINS.

The foliage of the trees reflects a considerable part of the solar rays which reach it, and this heat is reflected in all directions. That part which passes toward the sky is probably lost, and plays only a small part in warming the air. The part which is reflected longitudinally or at downward angles has a very favorable path for absorption by the air, more favorable in fact than that of the noonday direct rays of the sun. The absorption of this heat should occur, for the most part, in the vicinity of the forest. The temperature around the forest ought, therefore, to reach a somewhat higher maximum on sunny summer days than that of the air at some distance from the forest.

On the other hand, the surface at the stations near the forest is exposed to nocturnal radiation of heat to the sky about as freely as is the station at a distance, and, as the former is often in the lee of the forest, its air is generally more stagnant. This promotes cooling of objects at the surface of the earth, and as the station near the forest is as much exposed to celestial radiation and the relative stagnancy of the air favors this cooling, and also favors the communication of it to the adjacent air, the temperature at such stations should often fall lower than

over a plain distant from woods. The forest-field or forest-glade station is, therefore, not exactly like a station in an open plain. It is likely to average a little warmer in the day and a little cooler at night, giving it a greater daily amplitude not only than that under trees, but greater, too, than that in open prairies. Whether the mean temperature would be different in the forest-field station would depend on the relative increase in maximum and minimum. If the increase in the former is greater, the forest-field station temperature would be higher than that of the prairie station; if the minima exaggeration is greater, it would be the opposite.

The phenomena mentioned above are especially noteworthy in forest glades. The horizontal reflection from the foliage comes there from all sides, and the heat rays not absorbed are reflected from the opposite side, a part to the sky, a part to the opposite side, and this reverberation of the heat makes such places oppressively hot in the early afternoon. This is well known to the hunter and to the pioneer with his little clearing in the deep woods. Again, as the closed glade is in the lee for winds from all directions, the air is always somewhat stagnant and clear weather celestial radiation must always make a lower minimum temperature than where there is free circulation of air. The field station, when there is a pair, one in the forest, the other near by in the field, must always have something of the glade character in its temperatures, and the data given at this point must be somewhat affected by it. The relations for range of temperature, as between the interior forest and its external station should show this, and the ranges should be somewhat greater than between forest and plain. Whether there is an exaggeration of the mean values of $W-O$ can only be told by observation. Fortunately the plan of the Swedish observations included and was rather devoted to this particular side of the problem. The stations were really of four kinds. The first were under woods, of which there were but three. The second were the parallel field stations for the three forest stations. These were usually located in an "endroit libre" (opening), but the distance of the forest in all directions is given, so that this means a "glade" of greater or less size. The third class were stations in "clairièré" (clearing), with the distance from woods in all directions (and not very great). Each of these also signifies a "glade," but large and unlike the preceding. It has no corresponding forest station. The fourth class comprises stations in large open places, far from forests. These are stations in the plain. This distribution of stations affords the great advantage of permitting a study of the average amount of change due to the "glade" position of a station and thus enabling us to pass from the relations between parallel stations to those between wooded and treeless districts. It has, however, the disadvantage that the stations are not strictly comparable, as in the "parallel" system, and as would be the case in the "radial" system. This difficulty can be in large part overcome by the careful selections of

stations, and this Dr. Hamberg, as appears from his discussion of the Swedish results, has endeavored to make.

The deductions of Dr. Hamberg have been taken without change, except in reducing the units to the common English ones. The air observations were taken at a height of 1.8 meters (5.9 feet). The series of observations discussed for temperature are usually from three to five years' duration. The mean annual results are shown in Fig. 45. In

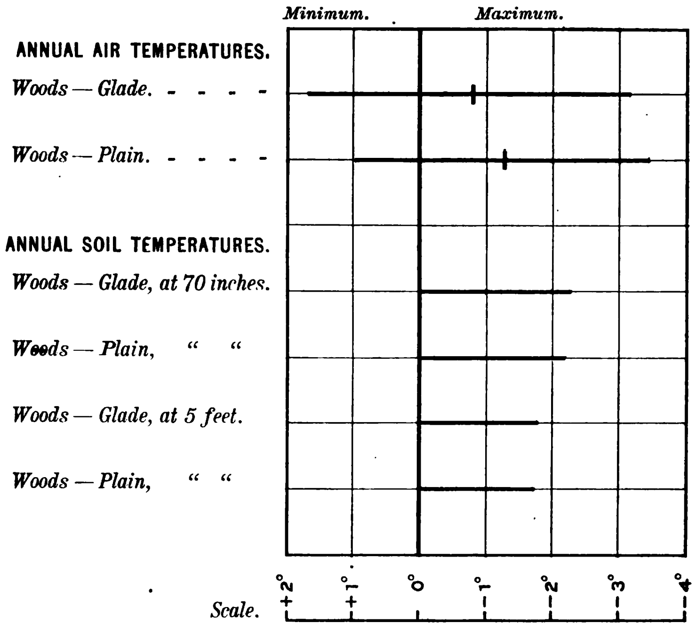


FIG. 45.—Differences of mean annual temperature between woods and glades and woods and plains, Swedish observations.

the air temperatures the maxima are higher in the woods as compared with the glades and as compared with the plains. They are, therefore, erected above the zero line. The maxima are reduced in both cases, and they are let fall below that line. It appears at once that the mean range is larger (the total line longer) for the reduction by wood as compared with plain. If the comparison of woods with glade be *W—G*, and wood with plain *W—P*, then the following exhibits the differences:

Temperature differences in woods, glades, and plains.

	W—G.	W—P.	G—P.
	Degrees.	*Degrees.*	*Degree.*
Maxima	—3.06	—3.24	—0.18
Minima	+1.53	+0.99	—0.54
Mean	—0.76	—1.13	—0.36
Range	4.59	4.23	0.36

The range is exaggerated in the glade as compared with the plain by 0°.36. The minima are also exaggerated in the plain by 0°.54, but it appears that in this case the maximum is reduced.

The disappearance of this feature of glade temperatures is doubtless due to the large size of some of the glades, and also to the high latitude of the stations, giving a low latitude to the meridian sun. The relatively large reduction of the maxima causes the mean temperature of the glade to be 0°.36 lower than that of the plain. It appears, therefore, that the glade climate is by a small quantity more rigorous than the climate of open plains. The forest tends, in so far, to exaggerate or sharpen the diurnal changes of temperature.

Fig. 45 also shows the values of $W-G$ and $W-P$ for soil temperatures at the depths of 20 inches and of 5 feet. The temperatures are slightly higher under plains; $G-P$ at both depths $= +0°.1$.

Fig. 46 shows the monthly values of $W-G$, $W-P$, and $G-P$. The

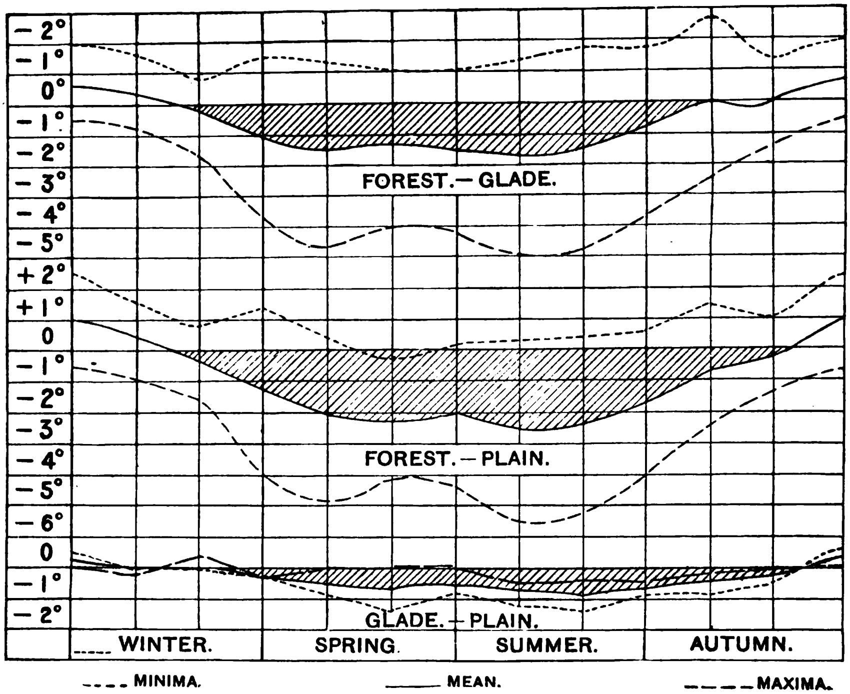


FIG. 46.—Differences of air temperature in forest, glade, and plain (Swedish).

stations are not necessarily the same for the three figures nor the same as for the preceding. The first curve is of the same character as the temperature figures in the preceding sections, and shows the same general features. The cooling effect is much more marked in the spring than has been the case with any examined before. The second shows an exaggeration of the features of the first, except for the line of minima, and these appear in spring and summer to be much the same in forest and plain.

The third figure enables us to compare the differences between glade and plain. They are small, but curious. The line for minima (dotted line) and for maxima (broken line) have changed places. The maxima are reduced generally, though slightly, in glades as compared with plain, but the minima are exaggerated by a quantity two or three times as large. The result is that the glade is cooler in mean temperature for three of the seasons, and that its diurnal amplitude is sharpened or its climate made more rigorous. In winter the advantages are with the glade, in the other seasons against it.

To bring out more clearly the advantage in range possessed by the plain over the glade, Fig. 47 has been constructed. The distance from

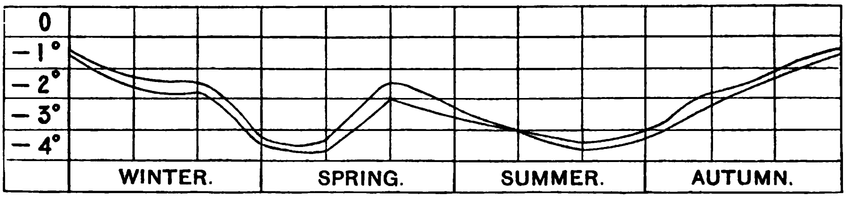


FIG. 47.—Amplitude of W—G (lower curve) and W—O (upper curve), Swedish observations.

the zero line to the first curve gives the reduction of daily amplitude in woods as compared with plains, to the second of woods as compared with glades. The distance between the lines is the difference in amplitude favorable to the plain as compared with the glade. It does not change sign during the year, and glade and plain are alike for only one month, that of July. Fig. 48 gives the temperature values of $W-G$

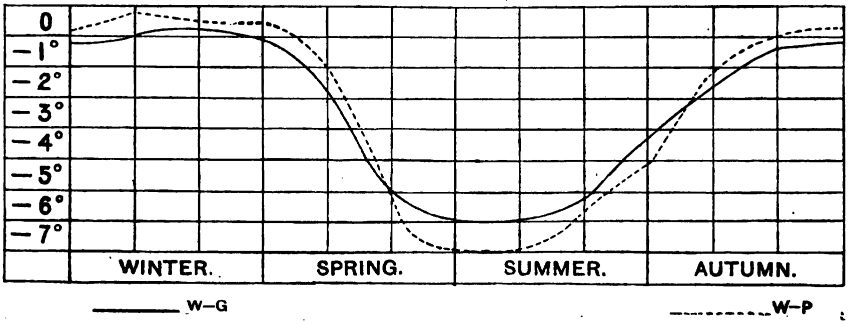


FIG. 48.—Difference of soil temperature at 20 feet in depth.

(unbroken line) and $W-P$ (broken line) for the soil at the depth of 20 inches. As is to be expected, the temperature of the glade soil is intermediate between that of the woods and that of the plain.

Dr. Hamberg also studied the effect of clear and cloudy weather on the differences between glade and plain. The following table gives the mean values of $G-P$ for clear and cloudy weather at the three hours of daily observation. The clouds cause the temperatures at the two stations to approach the same degree, reducing $G-P$ to zero:

Temperature differences in glade and plain.

	Clear.			Cloudy.		
	8 a.m.	2 p.m.	9 p.m.	8 a.m.	2 p.m.	9 p.m.
	Degrees.	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*
Winter	0	+0.9	—0.5	—0.2	0	+0.2
Spring	+0.5	+0.2	—1.4	+0.4	0	—0.2
Summer	0	—0.2	—1.8	+0.2	—0.2	0
Autumn	+0.4	+0.4	—1.3	+0.4	0	0
Year	+0.2	+0.3	—1.3	+0.2	0	0

Again, Dr. Hamberg studied the relations of this difference to the direction of wind, and found the effect to be very slight, perhaps not appreciable. The horizontal reflection of the rays of heat from the foliage could cause an area of greater maxima and the shelter from the winds an area of lower maxima about a forest. The two together would cause an area of greater amplitudes or more rigorous climate, and this has been directly observed by La Cour in Denmark. Observations were taken at a series of stations at different distances from the margin of the forest but at elevations above the sea, varying by only 10 or 12 feet. The result of twenty-four days' observation in the summer of 1867 in Jutland are given in the following table, where the corrections for differences of elevation are already made. The thermometers were arranged on a line from a northern to a southern forest:

Station.	Mean temperature.	Daily amplitude.
	Degrees.	*Degrees.*
200 feet within northern forest	56.8	9.2
At its margin	57.2	9.9
200 feet from margin	58.3	13.3
400 feet from margin	58.1	12.6
200 feet from south forest	58.3	13.3
At its margin	57.7	12.4
200 feet within it	57.2	11.0

It appears that the least amplitudes are in the forest and the greatest at something over 200 feet, not less than 400 feet, outside. In this case the highest temperatures are at the same distance. A corresponding series of observations were taken on the island of Zealand, and a similar area of highest amplitudes was found.

CONCLUSIONS REGARDING TEMPERATURES WITHIN AND WITHOUT FORESTS.

This completes the review of the direct comparative observations of temperatures in woods and without. While the observations show, like all other meteorological phenomena, very great variations due to soil, topography, latitude, and many other agencies, they permit us to draw a series of conclusions which may be considered as definitely established in their general features. They are—

(1) There is one season only of marked forest action and that is the warm season. The action is most marked in the early summer months.

(2) In the forest during this season the maxima of temperatures are lowered, the minima are raised, the mean is lowered by a degree or two, and the daily range is reduced by several degrees. This action decreases slowly up to the level of the foliage, then rapidly, disappearing at a score or two of feet above the foliage.

(3) The forest litter plays an important part in preserving the temperature of the forest soil.

(4) The vertical temperature gradient through the forest is reversed; it is greatest at the level of the foliage, decreasing slowly downwards but rapidly upwards.

(5) The diurnal amplitude increases from the margin of the forest outwards to a distance of a score or so of rods, where it reaches a maximum. The amplitude is also greater in glades. Hence the extremes of temperature are exaggerated just outside the forest.

(6) As a result of the discussion of tree temperatures and the organic sources of warming and cooling in the plant, it may be added that—

(7) The changes of heat due to organic processes are not sensible except, possibly, the cooling due to transpiration. The heat used in this process is an appreciable fraction of the heat from the sun's rays and the cooling due to it may lower to the point of frost a temperature already falling from general meteorological causes.

TEMPERATURES IN WOODED AND TREELESS TERRITORIES.

In passing to the subject of temperatures and forests in its broader aspect, namely, in so far as it relates to differences in wooded and treeless territories that are situated widely apart, the strict comparability of the stations is lost. The stations to be compared are distant from each other at different elevations above sea level, in different latitudes, and, possibly, members of different meteorological services, with all the differences in instruments and methods which that implies. These differences in the stations can not be so perfectly neutralized by applying corrections to the observations as entirely to satisfy the critical reader, because the corrections are themselves uncertain and they often surpass in quantity (for instance, the corrections for altitude) the amount of change which forests might be expected to make. Besides, it is often impossible to say when a difference is found that this is due to the forests. It may be due to other causes, for instance, the coolness of evaporation in regions of heavy rainfall, and the existence of the forest may be due to the very difference found. These difficulties may be evaded more or less completely in certain definite cases, and it is the published cases of this sort which will now be given. The case of Vienna and its surroundings, discussed by Dr. Hann, is one of the most satisfactory. It

is the case of the temperatures in open fields about Vienna and in the Vienna forest. The elevations vary by less than 200 feet and the observations are corrected for the variation. The mean temperatures about Vienna are obtained from four stations.

Stations near Vienna.	Latitude.	Elevation.	January.	April.	July.	October.	Year.
	48+	*Feet.*	°	°	°	°	°
Hohe Warte	15′	663	29.5	49.3	67.8	50.2	48.7
Neue Sternwarte	13′.9	847	29.3	49.1	67.6	50.2	48.6
Mödling	5′	787	30	49.6	68.4	50.7	49.3
Perchtoldsdorf	7′	853	29.8	49.3	68.9	50.7	49.3

The best forest station for the comparison is Hadersdorf, 18 miles southwest of the Hohe Warte, and its altitude differs from this by 92 feet. If the second or cooler pair of stations in open country near Vienna be represented by *A*, the first or cooler by *B*, and the observations at Hadersdorf by *C*, the comparison stands as in the following table.

	Latitude.	January.	April.	July.	October.	Year.
	° ′	°	°	°	°	°
A	48 6	29.9	49.4	68.7	50.7	49.3
B	48 14.5	29.4	49.2	67.7	50.2	48.6
C	48 13.	28.6	47.7	65.5	48.7	47.1
C–B	....	–0.8	–1.5	–2.2	–1.5	–1.5

This table shows that there is an appreciable cooling in the Vienna forest and that this is greatest in summer and least in winter. The forest consists of beech trees only.

A detailed comparison also brings out a curious fact. The temperature in the forest region is nearer that in the open region at the 2 p. m. observations than for that at the 9 p. m. observations. The monthly means for the years 1875–1884 give the Hadersdorf temperature as 0°.2 higher to 0°.7 lower than the Hohe Warte temperature at 9 p. m., 1°.1 lower to 4°.5 lower, the difference being greatest in the summer months. The 7 a. m. observations are intermediate, varying from 1°.1 to 2°.2 lower at Hadersdorf. The explanation of this is probably to be found in the fact that the station at Hadersdorf is, in some sort, a glade station. The thermometer is not under trees, but is on the north side of a building under the usual Austrian shelter. As already pointed out, the glade has a greater range than the open field, and its maxima and minima must fall at about the same hour of the day. If the 2 p. m. observations were deferred an hour or two, the temperatures at Hadersdorf would probably be higher than at Hohe Warte.

The stations in forest regions used in making these general comparisons are not likely to be under trees. They are the ordinary meteorological stations, and while in wooded territories, they could not properly be established under the shelter of the compact foliage of a forest.

They are generally in larger or smaller open places, generally on the north side of the building. They are, therefore, often of the nature of "glade" stations. While they will not show the relation between the interior air of forests and the surface air of prairies, they will bear on the practically more interesting question of the differences between these spots of a wooded region which are occupied by man and the prairie or plain, or the treeless region. The results, however, will differ somewhat from those obtained by a system of parallel stations.

The meteorologist who has published the most elaborate study of this subject is Dr. Woeikoff, who has devoted a chapter to it in his book on the climates of the earth. A striking case given by him in some detail is that of northern India. April to July are here the hot months. From July on the heat is tempered by abundant rains. The temperatures are compared, for the hot months, over a territory that includes the three different characters of treeless, transition, and wooded. In the first the vegetation is already burnt up by March, except for small stretches where irrigation is practiced. The third is the great forest region of the middle course of the Brahmaputra and its southern tributaries, where the surface is covered with the densest forests, and the openings are little else than islands in the sea of forest. The transition region lies over the delta of the Ganges and northward and has no extended forests, but groves and scattered trees and abundance of bamboos. The table which follows is Dr. Woeikoff's, except that for the most of the stations the temperatures have been taken from a later publication, that of Mr. Blanford's "Climates of India."

Station.				Mean temperature.					Mean maxima.		
Name.	Lat.	Alt.	Distance from sea.	Year.	Apr.	May.	June.	July.	Dec.	Year.	Apr. and May.
Open territory.	°	*Feet.*	*Miles.*	°	°	°	°	°	°	°	°
Agra	27	555	679	79	88	94	95	87	62	116	106
Lucknow	27	369	533	78	87	92	92	86	61	114	104
Allahabad	25.5	307	432	78	88	92	91	85	61	116	106
Patna	25.5	183	303	78	87	89	88	85	62	110	101
Burhanpur	24	66	161	78	85	85	84	83	66	109	101
Intermediate territory.											
Sangod	21.5	26	0	79	82	85	85	83	67	......	....
Durbunga	26	116	337	77	84	85	85	84	63	105	96
Purneah	26	125	283	77	84	83	84	84	63	105	98
Forest territory.											
Silchar	25	104	131	76	78	80	82	82	66	99	87
Goalpara	26	384	249	76	78	78	80	81	65	......	....
Sibsagar	27	333	364	73	74	78	83	84	61	99	86

The fall of the temperatures in the hot months as the forest is reached is very noticeable, and it is still more so in the reduction of the maxima. The cooling in the forest region even appears to surpass that due to proximity to the sea. It is true that this difference in temperature may be in part due, as has been claimed, to other causes. The tem-

perature in latitudes 20° to 30° N. seems to fall slowly from Western India to China and Tonquin, but Dr. Woeikoff finds that it rises in the east, in the hot seáson, where there are extensive treeless regions, and instances Hanoi, in 21° N., where the annual temperature is 75°.6, May 83°.8, June 88°.2, July 86°.9.

Dr. Woeikoff also gives series of temperatures near parallels of latitudes across Europe and into Asia. A correction of 0°.9 is made for each degree of latitude, and of 1°.3 for each 100 meters of elevation. All temperatures are reduced to a uniform elevation of 200 meters (656 feet). The order is always from west to east.

Mean temperatures for July on the parallel of 52° N.

	Degrees.		Degrees.
Valentia	57.6	Orel and Kursk	67.6
Leipsic	62.6	Poljänki	65.7
Warsaw	64.7	Orenburg	69.1
Tschemigow	65.1	Akmollinsk	70

The mean temperature is lowest on the Atlantic coast. It rises up to Poland by seven degrees, then remains steady over the forests of the Bug and Dneiper, then rises over the black-earth region of Central Russia with extensive cultivation (Orel and Kursk), falls again in the forests over the sources of the Sura (Poljänki), to become again higher over the Kirghiz steppes.

July mean temperature along 50° N.

	Degrees.		Degrees.
Guernsey	59.5	Troppau	68
Brussels	62.6	Arvavarallja (Carpathians)	64.2
Würzburg	68	Lirow (Lemberg)	65.5
Promenhof (N. W. Bohemia)	64.4	Kieft	66.2
Prague	68	Charkow	68.4
Hochwald	63.9	Semipalatinsk	72.7

The temperature increases rapidly to the Main valley, then rises and falls over the forests of Bohemia and the Carpathians, becoming hardly higher at Charkow, where there remains some forest, than at Würzburg. Eastwaru from here it rises rapidly.

July mean temperatures along 48° N.

	Degrees.		Degrees.
Brest	62.2	Bistnitz (Transylvania)	68
Versailles	65.5	Czernowitz	68.9
Carlsruhe	66.6	Ekaterinoslaff	71.6
Vienna	67.8	Lugau	72.5
Debreczin (Hungary)	70.7	Irgis (steppes)	75.6
Rosenau (Hungary)	68.9		

Here the rise is about eight degrees from the Atlantic to the prairies of Hungary (Debreczin). It is cooler in Eastern Hungary and in Transylvania, where there is yet much forest. Czernowitz is near the

South Russia steppes, but it escapes their warming influence by the beech forests around it. This is the eastern limit of the beeches.

July mean temperatures on 46° N.

	Degrees.		Degrees.
La Rochelle	66.7	Oravicza Mountains, Southeast Hungary	67.5
Milan	62.9	Pojana Ruska (Hungary)	67.8
Trieste	72.7	Odessa	71.2
Agrau	71.1	Chersson	72.5
Szegedin (Hungarian prairies)	71.6	Astrakan	75.6
Arad (Hungarian prairies)	73		
Raimsk and Kasalinsk	76.1		

The high temperature of Trieste agrees well with its bare and burnt surroundings. In Croatia, far from the sea and where there are woods in the plain, it is cooler, warmer again in the Hungarian prairies, but 5° or 6° cooler in southern Hungary and Banat, where the vegetation is luxuriant.

July mean temperatures along 42° N.

	Degrees.		Degrees.
Oporto	67.6	Poti	70.9
Rome	75.2	Tiflis	78.8
Ragusa	74.5	Kutais	73

Poti is in the midst of the swamps and forests of Mingrelia and its temperature is 4° lower than in the Dalmatian towns on the Adriatic. Even Kutais is cooler than Ragusa, though the former lies far in the interior and the forests have been cut freely in its vicinity.

July mean temperatures along 38° N.

	Degrees.		Degrees.
Lisbon	70.5	Smyrna	77.9
Campo Major	76.3	Lenkorau	74.7
Palermo	76.5	Krasnoodsk	82.0
Athens	76.2		

The low temperature of Lenkorau is especially noteworthy because it is deep in the interior of a continent and the cloudiness and rainfall are light. Yet in the vicinity are extended forests with luxuriant vegetation. It is on the Black Sea, while Poti is on the Caspian. Near both are extensive forests. If the July temperature is reduced to 42° N. but not corrected for elevation it proves to be 73°.6, only 0°.4 higher than that of Poti.

Dr. Woeikoff also calls attention to the remarkable relations of Bosnia, Herzegovina, and Dalmatia, along latitude 44° N. The temperatures are here the annual means.

	Degrees.		Degrees.
Banjatella, Bosnia	70.3	Klissa, Herzegovina	74.8
Dolnja Tusla, Bosnia	68.2	Mostar, Herzegovina	76.1
Trawnik, Bosnia	70.3	Knin, Dalmatia	73.6
Serajewo, Bosnia	69.3	Lissa, Dalmatia	72.3

Here it appears that the densely wooded Bosnia is 5° or 6° cooler than rocky, nearly treeless Herzegovina, and even cooler by 2° or more than the small island of Lissa, which is exposed to the full influence of the Adriatic.

All this goes to show that in the western part of the old world the presence of large forests has a very sensible influence on the temperature, so much so that the gradual rise of temperature from west to east is almost invariably broken by it.

Comparisons similar to those of Dr. Woeikoff can be made along parallels in the United States with results similar in character but not so striking in quantity.

The writer has made this comparison for the parallels which follow. The data are taken from the annual reports of the Chief Signal Officer.* They are reduced to a common elevation of 1,000 feet above sea level. No reduction is made for latitude, but the stations used are selected not far to the north or south of the chosen latitude.

Temperatures along parallel 38° N.

	Latitude N.	Altitude.	Annual mean temperature.	June temperatures.			December temperatures.		
				Mean.	Max.	Min.	Mean.	Max.	Min.
	°	*Feet.*	°	°	°	°	°	°	°
Lynchburg	37	652	57	73	82	64	40	47	30
Louisville	38	551	56	72	82	64	38	45	30
Cairo	37	359	56	74	81	66	37	44	29
St. Louis	39	571	54	72	82	64	33	42	27
Leavenworth	39	842	53	73	83	63	30	40	24
Dodge City	38	2,517	56	79	91	67	34	47	26
Las Animas	38	3,899	58	80	96	66	35	52	24

Leavenworth lies near the margin of the wooded and treeless district, but in no case are the woods heavy and unbroken. The mean temperatures show no unmistakable effect of the woods, but there is an evident difference in the December temperatures and a still more marked difference in those of June. The difference is most marked in the extremes, as was to be expected. This is most clearly shown in the mean amplitudes obtained by taking the minimum from the maximum. The amplitudes for December at stations in the order given in the above table are 17°, 15°, 15°, 15°, | 16°, | 21°, 28°. The change at the edge of the plains is very noticeable. For June the amplitudes are 18°, 18°, 15°, 18°, | 20°, | 24°, 30°, with the same change as before.

This comparison is not entirely convincing of the effects of forests, because with the change of condition as to trees there is a large change of elevation, so large that the correction for it surpasses by far the difference which may be expected from the action of forests. This difficulty can not be entirely overcome in the American stations, for the plains form an interior table-land, but individual pairs of stations can

*1885, pp. 82–84, and 1886, pp. 408–411.

be selected, otherwise suitable and where the differences of elevation are less marked. Such are given in the accompanying table. One station is in the wooded district, the other in the plains, and they have been selected with reference to being in the same latitude, to being as near the margin as possible, and to having at the same time only moderate differences of elevation.

Mean temperatures for stations in pairs.

	Lat. N.	Altitude.	Annual mean temperature.	June temperatures.			December temperatures.		
				Mean.	Max.	Min.	Mean.	Max.	Min.
	°	*Feet.*	°	°	°	°	°	°	°
Little Rock	34.7	288	60.0	75.3	85.7	67.4	43.4	50.9	35.2
Fort Sill	34.7	1,200	60.8	73.1	90.5	67.8	38.2	53.1	37.1
Fort Smith	35.4	451	57.7	75.0	87.5	65.7	39.2	50.8	30.6
Fort Elliott	35.5	2,650	60.7	82.1	92.3	67.7	38.1	52.7	28.3
Davenport	41.5	615	49.1	68.4	76.6	58.9	26.9	34.9	19.3
North Platte	41.1	2,841	53.3	75.6	87.6	64.9	28.1	42.9	20.8
Moorhead	46.9	926	36.4	64.5	75.6	52.2	9.5	20.1	0.4
Bismarck	46.8	1,694	41.2	67.9	78.6	55.6	11.9	26.6	6.7
St. Vincent	48.9	804	32.6	61.4	73.1	48.8	4.0	14.7	5.8
Fort Assinniboine	48.5	2,720	45.8	69.9	82.5	58.4	21.5	32.8	14.1

The mean annual temperatures are persistently lower at that station of the pair which is situated in the wooded district. The same is true of the mean June temperature, while it is reversed for the December one. The maxima are lower at the stations in the wooded area and also, generally, the minima. The mean monthly amplitudes for each pair for June are 18°.3 to 22°.7, 21°.8 to 24°.6, 17°.7 to 22°.7, 23°.4 to 23°.0, 24°.3 to 24°.1; for December they are 15°.7 to 16°.0, 20°.2 to 24°.4, 15°.6 to 22°.1, 19°.7 to 19°.9, 20°.5 to 18°.7. They are generally larger at the station on the plains—always so at the lower latitudes.

It appears, therefore, that wooded districts have an advantage in temperatures over treeless areas. The forests lower the mean temperature slightly and also cut down the range.

There has been much discussion over evidence of change of temperature at individual stations, or over more extensive areas, which might accompany changes in the quantity or distribution of the forests. The general opinion is that the data are not sufficient to give satisfactory conclusions. To be sure of a change, one must be sure of a definite and marked change in the amount of forests and must also be sure of the temperatures before and after the change. The first requirement is not without its difficulties, and the second is usually impossible. The early observations, if any were taken, are always defective in methods, instruments, and the care given to them. A variation in the exposure of the thermometer alone might cause a greater difference of mean temperature than we would expect to find between forests and prairies.

RELATION OF EVAPORATION TO FORESTS.

The amount of evaporation depends especially on the temperature, the wind, and the amount of vapor already present in the air. The first two are much changed by the presence of the forest, and it is to be expected that the evaporation in and about woods would show some peculiarities. The evaporation varies very much also with the character of the surface from which it proceeds. Some surface must, therefore, be taken as a standard for evaporations, and the measurements be made with reference to this. There is considerable variation in the standard surface selected, but in the German service it is that of water. The reductions have been made, in this section, to terms of evaporation from a water surface. At the same time, since the evaporation is chiefly of meteorological interest because of its relations to precipitation, the amount of the latter is also included in the comparisons. The observations were carried on in the open fields and in the forest. The instrument employed is described on page 39.

Fig. 49 exhibits the comparison of the annual evaporation in fields

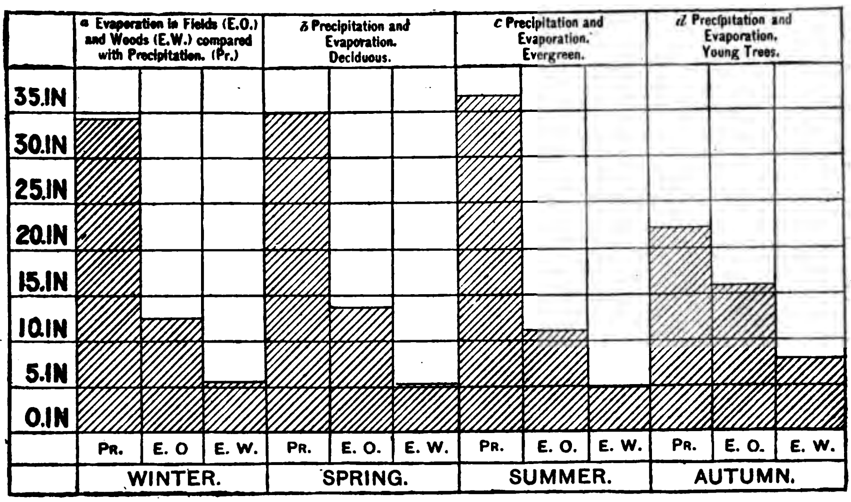


FIG. 49.—Evaporation and precipitation.

(*E O*) and woods (*E W*) with the precipitation. It will be noted that the evaporation under trees is about one-half of that in open fields. The precipitation is that of the open fields and, for the German stations and years reduced (the ten years, 1879 to 1888), its annual value was 34.3 inches (871 mm.). The evaporation in the fields for the same stations and time was 12.7 inches (322.5 mm.) annually, and that in the woods 5.4 inches (137 mm.). The corresponding percentages of evaporation were 37 and 16, showing a saving of 21 per cent, of the precipi-

tation by the woods. Fig. 50 exhibits the distribution of the evaporation for the year. The upper line represents the progress for the water surface in the open air, the lower that for the same in the woods. The shaded space indicates the saving, in inches, of a sheet of water

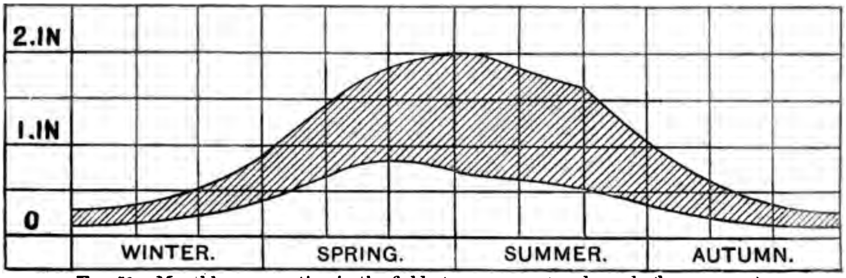


FIG. 50.—Monthly evaporation in the fields (upper curve) and woods (lower curve).

which is affected by the cover of the forest in lessening evaporation. The evaporation and its saving by the woods are both greatest in May and June and they decrease symmetrically on each side of these months. The amount in the winter months is very small, and it is, moreover, somewhat uncertain, as it is difficult to make the observations at that

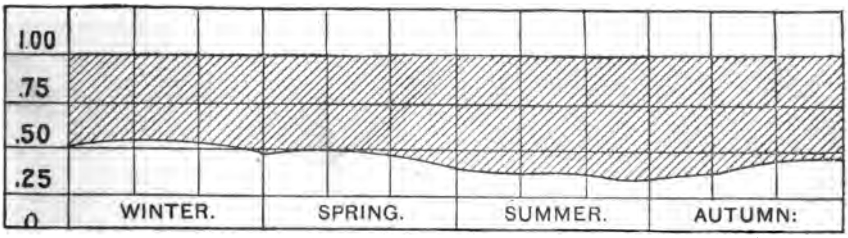


FIG. 51.—Percentage of evaporation in the woods as compared with that in open fields.

season. The annual evaporation in the woods is 44 per cent of that in the fields. Fig. 51 represents the percentage for the different months of the year. The upper straight line stands for 100 per cent, or the evaporation in the fields during the year, and the curve below represents the percentage in the woods. The shaded space is the percentage

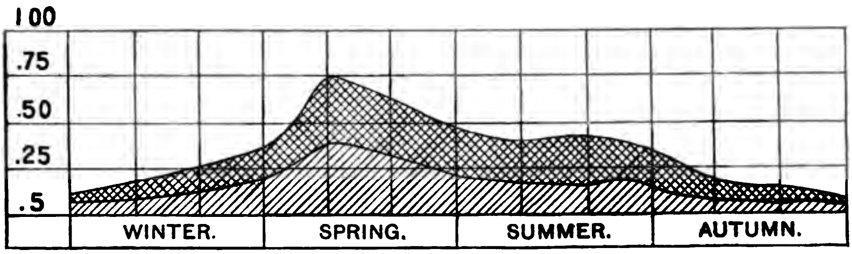


FIG. 52.—Ratio of evaporation from water surface in field (upper curve) and forest (lower curve) to precipitation (top line).

of field evaporation which is saved by the forest. This covers a full half of the diagram, with some addition to this from May to November. It is also interesting to compare the evaporation from a water surface with the precipitation from month to month. This is done in Fig. 52.

The upper straight line represents precipitation, while the upper curve represents evaporation in the fields, the lower that in the forest. Previous diagrams showed that the amount of evaporation increased rapidly up to May and June; this one shows that the percentage of rain evaporated increases even more rapidly and reaches its maximum in April, a month earlier. From this point it descends more slowly to the winter months, when the minimum is reached. Almost the same course is taken by the evaporation within woods. The hatched spaces below represent the percentage of precipitation evaporated within woods and without, the cross-hatched part that saved by the woods or evaporated in open fields in excess of that evaporated in woods. The saving is greatest at the time when the evaporation could dispose of the largest eprcentage of precipitation, namely, in spring and summer.

It is interesting to see whether the evaporation phenomena present any difference with different kinds of trees or with trees of different ages. Figs. 49*b* and *c* exhibit the annual quantity of precipitation and evaporation for stations under and outside of deciduous and evergreen trees respectively. It will be noticed that the saving of evapo-

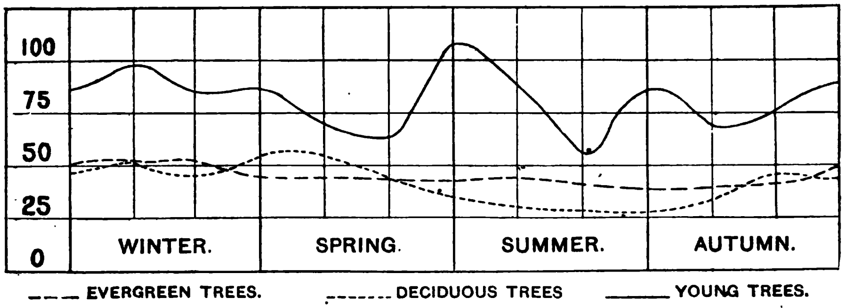


Fig. 53.—Percentage of evaporation in woods to that in the open air

ration under trees is more marked for deciduous trees. The percentage of evaporation in forests to that outside is 41 for deciduous trees and 45 for evergreens. Fig. 49*d* gives the same data for young trees. It will be noticed that the percentages are here entirely changed. The evaporation in fields approaches the quantity of precipitation (which is here small), while the evaporation under trees hugs closely that in the open. The evaporation in the open is here 73 per cent of the rainfall while that under trees is 58 per cent, which is 80 per cent of the former.

Fig. 53 gives the percentages of evaporation in woods compared to that outside for the various months. That for deciduous trees (the dotted line) varies more during the months and sums up slightly less for the year. The effect of the leafless condition in early spring is faintly visible.

The unbroken line represents the percentages for young trees. It is very uneven (on account of the series of observations, only seven years), but it runs much higher and occasionally the evaporation under the trees is greater than that outside.

Dr. Ebermayer's series of observations included more elaborate ones on evaporation than those of the German service. In addition to the evaporation from a water surface he also measured that from bare soil outside the forest and within, and that from soil in the forest which was covered by forest litter. The latter observations were made only in the months from April to October. His instruments were first a simple one, somewhat like that of the German service already described, and then the evaporometer of Lamont. The evaporation from earth, either naked or covered with litter, was measured by an apparatus which worked on the principle of the student lamp and kept the earth always saturated. The vessel containing the earth is of zinc. The instruments are protected from the sun, rain, and snow, but the air is given free access to them. The following table gives the percentages which are derived from his results, with some corresponding ones from the German stations to permit comparison. The evaporation from a water surface is the mean for six stations for three years; the other evaporation percentages are for two, with the exception of two months. The precipitation is for one year. The percentages are always made from the averages for corresponding years. The data from the German observations are for ten years.

Evaporation in woods in per cent of evaporation in the open.

	Dr. Ebermayer's results.						German observations.		
	Water surface.		Bare soil.		Soil under forest litter, and within forest.	Rainfall.	Water surface.		Rainfall.
	Open.	Woods.	Open.	Woods.			Open.	Woods.	
April	1	.45	1.15	.64	.27	1.75	1	.51	1.37
May	1	.43	.91	.37	.16	.68	1	.47	1.35
June	1	.36	1.07	.38	.14	1.46	1	.41	1.91
July	1	.35	.89	.34	.12	1.02	1	.38	2.33
August	1	.34	.87	.36	.11	1.00	1	.36	1.98
September	1	.33	.92	.39	.11	.59	1	.35	2.54
October	1	.41	1.26	.44	.18	3.45	1	.37	8.49
May-September	1	.36	.93	.35	.13	.95	1	.39	2.02

This table brings to light several interesting facts. The ratio of evaporation without and within woods is about the same in the two services, giving confidence to the generality of these figures. It appears, however, that the evaporation from a bare soil is about the same as that from a water surface. This is very large and is probably due to the fact that the soil is always kept saturated. The ratio between evaporation from bare soil within woods and without is about the same as that for the water surface.

The most striking feature of the table is the effect of the presence of forest litter on the evaporation from the soil within forests. The character and depth of this litter would make much difference, and it was probably kept as nearly as possible like that lying naturally in undisturbed woods. In this series of observations, even with saturated soil

underneath, it permits an evaporation of only 0.13 per cent of a free water surface. About seven-eighths of the evaporation from the forest is cut off by the woods and litter together.

The ratio of evaporation from a water surface to the precipitation for the same months is surprisingly large. According to these observations 5 per cent more than the precipitation during the warm season could be disposed of by evaporation from a water surface. Many surfaces permit a readier evaporation, and if we add to evaporation from a meadow, for instance, the large transpiration from the grass, it would appear that on the average more water must be evaporated than falls during this season, which is very improbable. The German observations give a more probable value, that of one to two. Evaporation is very readily affected by slight causes, and it appears probable that Dr. Ebermayer's instruments, or their exposure, may give occasion to an increase of evaporation as compared with the German stations. The annual rainfall is about the same for the period for which results are published from the two services—34.3 inches (871 mm.) in the one case, 34.5 (876 mm.) in the other. The amount of water returned into the air over a forest is a quantity worth knowing, even though roughly approximated, especially if it can be compared with that from other forms of vegetation and from bare soil. The forest air is furnished with vapor by the forest through transpiration from the trees, through evaporation from the soil, and through evaporation from the trees. The transpiration has already been estimated at 6.5 inches. This (and other special action of the forest) is practically confined to the warm season, which may be considered as extending from May to September, these months included. The evaporation from a free water surface in the open at the German stations for this time is 8.39 inches (213 mm.). The transpiration is, therefore, $6.5 \div 8.39 = 0.77$, or 77 per cent of this evaporation.

The evaporation from the soil under forest litter is, according to Ebermayer, 13 per cent of that of bare soil in the open in the warm season. Dr. Wollny has carried on several series of observations on evaporation through a forest litter, and from these it appears that the litter reduces the evaporation by one-fourth or one-third. This would give three-fourths of 0.39 or two-thirds of 0.39, which are 0.30 or 0.26, numbers considerably larger than Dr. Ebermayer's. As the latter's observations were made on an observational scale while Dr. Wollny's were only on an experimental one, we will take Ebermayer's result of 0.13 as the measure of evaporation in woods.

Only 70 per cent as much rainfall reaches the rain gauge in the woods as falls in the open fields, the rest is caught in the leaves or branches and moistens these and the trunk.

Very little runs down the trunk, as has been shown by the observations at Nancy.[1] This 30 per cent of rainfall must be again evaporated,

[1] This statement is based on observations made under one tree, the kind and conditions of which are not even stated, and the conclusions have been refuted by the

since the plant takes up little or no water in that way. We have, therefore, to add to the other forest additions to the vapor of the air 0.30 × 2.02 = 0.61 per cent of evaporation from a free water surface in the open air. To this should be added the amount of dew which is evaporated, but this is unknown, and as it is condensed from the adjacent air at night to be added to it again in the daytime, its omission will not make the result less significant. The moisture added to the air is, therefore, roughly, for the warm season:

By transpiration, .77 per cent of the free surface evaporation.
By interior evaporation, .13 per cent of the same.
By evaporation of rainfall, .61 per cent of the same.
Total, 1.51 per cent of the evaporation from a water surface in open fields.

To get the total in terms of the precipitation, this result is to be divided by 2.02, giving 0.75.

As to other forms of vegetation various estimates are given, but Dr. Wollny within a few years has made a series of careful measurements. From them, by reducing, we get—

For mixed crops and fallow, 1.44 of evaporation.
For clover, wheat, oats, etc., 1.73 of same.
For sod, 1.92 of same.

These values are conservative, other authors giving generally larger ones. The evaporation from bare soil varies much with the kind of soil and its degree of saturation with water.

As Dr. Ebermayer kept the soil constantly saturated, his results do not represent natural conditions. The evaporations from soil in open fields will be cut down by general lack of sufficient moisture to saturate them. Schubler's value of soil evaporation has, therefore, been used. By it the soil evaporates 0.60 as much water as a water surface sheltered from sun and wind, but otherwise freely exposed to the air. Tabulating the results, we find that the percentages of additions of moisture to the air over different kinds of vegetation are about as follows for the warm season:

Evaporations from various kinds of vegetation.

	Of evaporation from a free water surface.	Of precipitation.
Sod	1.92	.96
Cereals	1.73	.86
Forest	1.51	.75
Mixed, etc	1.44	.72
Bare soil	.60	.30

Austrian measurements of Riegler, published in the Journal of the Forest Experiment Stations in 1879, from which it would appear that the rainfall reaching the soil is increased by from 3.4 to 19.6 per cent through the water running off along the trunks, according to the kind of trees; the first figure referring to spruce, the last to beech. The total loss of water by interception may then be averaged to be 12 per cent of the rainfall instead of 30. See also p. 134 of this bulletin.—B. E. F.

It appears that the forest is of medium activity in this regard. It is usually surpassed by the ordinary forage crops, but surpasses ordinary fallow growths and far surpasses the average bare soil.

Still, the forest exercises a strong, conservative effect on the waters within and under it. It saves the most of its ground water from evaporation, and a great deal of the water above the surface. It differs from other forms of surface covering in drawing its water from a greater depth. It therefore does not dry out the surface so much, and it is also less sensible to temporary droughts. Although less effective, on the average, in adding vapor to the air than are many less herbaceous forms of vegetation, it is more steady in its action, and it therefore adds its moisture when it is most needed. During continued dry weather the roots of the grasses dry out the surface soil and exhaust its water. They then cease pouring moisture into the air. At such times the forest may continue its transpiration and at the same time, by its preservative action, its soil is charged with moisture and may continue to feed the springs tributary to it.

FORESTS AND HUMIDITY.

The psychrometer observations, within and without forests, permit a study of absolute and relative humidity. The comparative results for the absolute humidity are given in the accompanying table in the form of the values of *W—O*. The plus sign indicates a greater amount of vapor in the air of the forest; a minus sign the reverse. The units are hundredths of a millimeter of mercury as it would be shown in a barometer. The first part of the table is derived from the German observations. To it are added the values calculated from the observations in forest and glade (*W—G*), and in forest and plain (*W—P*), from the Swedish service.

	Winter.	Spring.	Summer.	Autumn.	Year.
At base of tree:					
General average	+ 2	− 3	− 5	+ 8	+0
Deciduous	+ 2	− 7	−11	+ 6	+2
Evergreens	+ 2	− 3	− 5	+ 8	0
Young	+ 9	+37	+26	+39	+37
At tree crown:					
General average	+ 1	+ 1	+10	+ 1	+3
Deciduous	0	− 1	−10	+ 1	− 2
Evergreens	+ 1	+ 2	+10	+ 4	+4
Swedish observations at base of tree:					
W—G	+ 7	+ 7	+15	+13	+10
W—P	+10	+13	+ 7	+ 7	+9

These numbers are very small, so small that, notwithstanding the absolute humidity is itself of small amount, they are usually less than 1 per cent of it. This is true of the German observations, except for the young trees. Here the value of *W—O* is always positive and reaches up to 4 or 5 per cent of the total absolute humidity. This

may be due to the surroundings of this station, which is on the Lüneburger heath, an immense tract of moorland occupying the eastern part of Hanover. There is no distinct difference between tree crown and base nor between glade and plain. In the individual stations the mean is frequently larger than the average of all, and is sometimes consistently positive, in other cases regularly negative. It appears, as might be expected, that there is no general difference between the absolute humidity in woods and outside, and the differences in individual stations may be due more to the surroundings of the station in open fields than to the forest. The lack of a characteristic absolute humidity in forests can be completely explained by the fact, already shown, that the forest is not an especially active producer of the vapor of water. Its position in this respect is intermediate; and even if it did produce a peculiarly large or a specially small amount of vapor it would not be apt to show a peculiar absolute humidity because of the rapid connection and mixture of gases. A gas spreads in all directions and with great rapidity usually from the point where it is produced. An observation by M. Becquerel illustrates the fact that a source of vapor need not give the air about it a higher absolute humidity. He compared, on a summer's day, the psychrometer readings in the air at 5 feet, just over a tree, just over garden vegetables, and just over a stream, and found the absolute humidities to be practically identical. However much these surfaces may have differed in the production of vapor, the rapid connection and mixture prevented this difference from being appreciable as absolute humidity of the air.

While the absolute humidity depends only on the amount of the vapor of water in the air, the relative humidity depends on this and on the temperature also. As a difference in temperature between woods and open fields has already been shown, there must be a difference in relative humidity, and as the temperature of the woods is lower the relative humidity must be higher, or the value of $W-O$ must be positive. The following table shows that this is the case:

	Winter.	Spring.	Summer.	Autumn.	Year.
At the base:					
General average	+2	+2	+6	+5	+4
Deciduous	+2	+1	+7	+5	+4
Evergreens	+2	+4	+5	+4	+4
In tree crown:					
General average	+1	+2	+3	+2	+2
Deciduous	+1	+1	+2	+1	+1
Evergreens	+1	+2	+4	+3	+2
Swedish observations:					
$W-G$	+1	+4	+4	+2	+3
$W-P$	+2	+5	+4	+2	+3

There is no great difference in the different cases. The surplus in the tree crown is a little smaller because the temperature is higher there.

M. Fautrat has carried on some observations of humidity above trees,

but his results, as published in the *Comptes Rendus*, are fragmentary. They are given in the accompanying table as they were published. The results in absolute humidity were not published. The observations over trees are compared with those at the same height over fields and about a thousand feet distant. The psychrometer was several feet above the trees in the case of the deciduous trees, but close to the top of the evergreens.

	Forest of Halatte deciduous trees.				Forest of Ermenonville evergreen trees.			
	No. of years.	W.	O.	W—O.	No. of years.	W.	O.	W—O.
January	0	......	......	......	0	......	......	......
February	1	87	84	+3	1	80	71	+ 9
March	2	71	69	+2	1	74	63	+11
April	2	64	62	+2	2	55	48	+ 7
May	2	64	61	+3	2	57	48	+ 9
June	2	60	57	+3	3	61	55	+ 6
July	2	60	57	+3	3	57	48	+ 9
August	1	56	54	+2	2	57	50	+ 7
September	1	77	75	+2	2	65	58	+ 7
October	1	80	77	+3	2	79	71	+ 8
November	1	82	79	+3	2	79	72	+ 7
December	1	83	81	+2	2	65	60	+ 5

The surplus of relative humidity over deciduous trees is not great, but that just over the foliage of evergreens is so large as to be significant. The published results do not admit of a ready computation of the absolute humidity, but the surplus of the relative is great enough to suggest a surplus of the absolute, large enough to be easily measured. The special, elaborate, and refined observations at Ried, in Austria, show slightly greater variations in absolute humidity than previous ones, and though they are nearly evanescent, some uniformity can be traced in them. As they were taken at irregular intervals they are not suitable for a general tabulation and their number forbids their being quoted at length. The conclusions reached by the discussion of them and given by Dr. Lorenz Liburnau are as follows:

The absolute humidity decreases in the forest from the soil upwards. The rate of decrease is usually the greatest under the trees and the least at the level of the foliage. The rate above the trees is intermediate between the other two. This rate is least in the late hours of the night, when it may be zero. It increases with the increase of the temperature of the air, becoming greatest in the midday hours, when, under exceptionally favorable circumstances, it may make a difference of 10 per cent, or even more. Occasionally, in high winds, the absolute humidity is greater over the trees. Over the field station the daily progress of the absolute humidity was about the same as in the forest, but the maximum difference was only about half as great. The absolute humidity in and above the forest is greater than that over the open fields, and there is some trace of an increase of this difference to the time of maximum.

The relative humidity decreases upwards in forests, but there is an occasional reversal of this at night. Over the open fields it decreases upwards with wet soil, but increases with dry. It is almost invariably greater about the forest, above as well as inside, over the field station, and it is higher above the forest than it is at 5 or 6 feet above the open field. The small significance of the vapor poured into the air by forests in raising the absolute humidity suggests the question of the relations of the forest to other constituents of the air. The forest takes up large quantities of carbonic acid, retaining the carbon and rejecting the oxygen. Does it sensibly change the relative quantity of either constituent so that the composition of the air is slightly different in the woods? Repeated observation shows that each constituent is curiously uniform in quantity in the free air. It has been thought the carbonic acid is quite variable, but the introduction of better methods of observation shows that, except in confined places where the gas is produced, the variations are very small.

A study of the numbers involved will show that the carbonic-acid gas taken up by a forest is a vanishing quantity compared with that which passes the forest in the same time with the moving air. Grandeau gives the annual product of carbon by a forest of beeches, spruces, or pines as about 2,700 pounds per acre. This corresponds to 9,900 pounds of carbonic-acid gas, or 69,300 cubic feet. Now, if the average motion of the air is 5 miles per hour (a light breeze, a low estimate), and the layer of air from which the gas is taken be estimated at 100 feet thick, there would pass over an acre 550,000,000 cubic feet in one hour. This air must contain about three parts in ten thousand of carbonic gas, and the total amount of the latter per hour is 165,000 cubic feet. But this is $2\frac{2}{3}$, or more than twice as much as that taken up by the trees in the entire season, so that the air could provide in thirty minutes for the wants of the trees for the entire season. If this season is taken at 5 months, or 150 days, the amount of air passing is $55 \times 10^7 \times 24 \times 150 = 198 \times 10^{10}$ cubic feet, and the amount of carbonic-acid gas is 594×10^6. The ratio of carbonic acid used to that furnished is only $\frac{69300}{594000000}$, or one part in 8,600.

The additions of oxygen to the air would form a still smaller percentage of the oxygen already present, for this gas makes up a quarter of the air instead of a thirtieth of 1 per cent.

The case is somewhat different with ozone, as it is formed in certain definite localities and its eagerness for combination is such that it can not pass far from its source before it will disappear. The resins of coniferous woods should be an abundant source of ozone, and although the decaying matter in and about woods provides abundant occasion for its disappearance before passing off into the outside air, still the amount of ozone in such woods should be sensibly greater than outside. Observation has not shown this unequivocally, but that may be due to the numerous imperfections of the method employed.

RAINFALL IN, ABOVE, AND NEAR FORESTS.

The first result from the parallel system of forest observations with regard to rainfall is the determination of the quantity of rain under trees as compared with that outside. Aside from any possible difference of rainfall over forests and outside, the tree and its foliage serve as a cover for the space underneath. The result is that the rain gauges under the trees fail to get as much precipitation as those which are in the open fields. Generally the rain gauges are alike in the two stations. Much difference is caused by the position in which the forest rain gauge is placed, whether under a crown of dense foliage or near its edge, or under the lighter foliage of smaller or scattered trees. Very little information is given on this point. The rain actually caught annually under trees in the German service varies from 89 per cent of that in the open (at Carlsberg) to 52 per cent (at St. Johann). The average is 75 per cent, or three-quarters; and ten of the sixteen stations do not vary 5 per cent either way from this mean. A twelve-years series of observations gives, for the three Swiss stations, 90, 84,

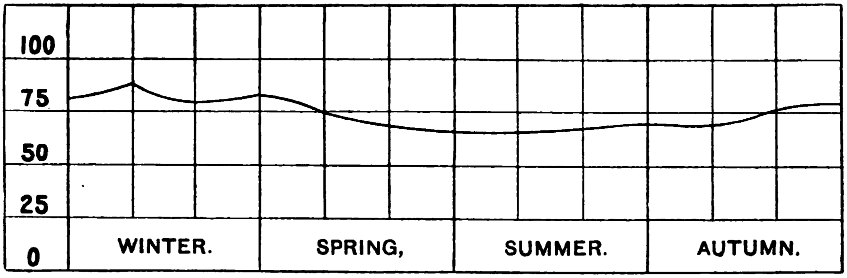


FIG. 54.—Percentage of precipitation, received under trees (all kinds)—German observations.

and 77 per cent, giving a mean of 84 per cent, considerably larger than that given by the German stations.

The station at Bellefontaine, near Nancy, also gives 84 per cent as the mean of eleven years of observation.

The proportion of the precipitation which passes through the foliage varies slightly with the season. Fig. 54 shows the relative amounts (percentages of outside precipitation) for the individual months. The percentage withheld is somewhat greater in the warmer season, though the difference is not great. Fig. 55 distinguishes between the evergreen and deciduous trees. The values for the evergreens are represented by the broken line. They appear very even, with only a slight tendency downwards in the warm season. The dotted line is the curve of the percentages for deciduous trees. It is less even than the other. The dip downward is decidedly more marked, but it is not great. It would seem that the advent of the foliage would have a much greater effect than that represented by the slight turn downwards of the curve

from April to June. The drop for deciduous trees during these months is from a percentage of 77 to that of 66, then to 65, making the foliage catch but 12 per cent of the precipitation, while the bare limbs and twigs in March caught 14 per cent, and in April apparently 23 per cent. The evergreen trees permit 73 per cent of the rainfall to pass through their foliage in April and identically the same in June. Admitting (though there are some reasons for doubt) that the rainfall is actually the same over a wood and a place outside but near, this small action of the foliage as compared with the branches and twigs requires explanation, and, whatever the explanation may be, it must apply only to deciduous trees, as evergreens show no difference in these months. No satisfactory explanation occurs to me. The catch in winter is largely influenced by the form of precipitation, the snow being caught temporarily and let fall later into the gauges below, but this would not affect the fall from April on.

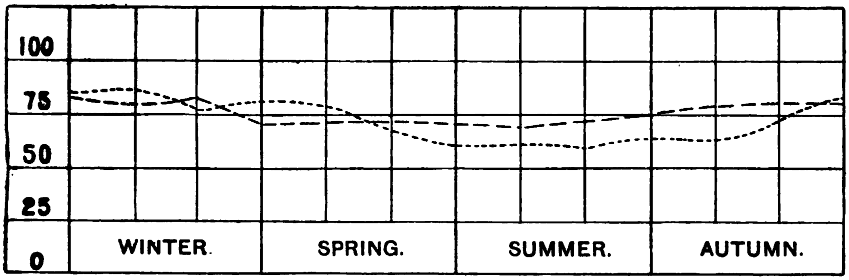


FIG. 55.—Percentage of precipitation, received under trees (different kinds).

The foliage catches more of the rainfall during the warm season, even in the case of deciduous trees. The percentages for the German stations are as follows, the warm season being taken from May to September, five months:

	Entire year.	Warm season.
General average	75	70
Average for deciduous trees	74	65
Average for evergreens	77	74

It seems that the deciduous trees withhold more of the precipitation (3 per cent) through the entire year than do the evergreens, and that this percentage additional becomes 9 in the leafy season.

Less than two-thirds of the rainfall in open fields, during this season, succeeds in reaching the gauge under deciduous trees; more than three-quarters reaches it under evergreens. This difference may be easily due to the character of the foliage in the two cases.

As an average from sixteen stations, and about 150 years of observation, it is found that, in the warm season, 30 per cent of the rainfall in

the open fails to reach the gauges under the trees. Taking all seasons together this deficit under trees is 25 per cent. The disposal of this water is easy to explain. It does not include the water that drips from trees, for this is fairly accounted for by the gauges. It is the water which moistens the tree and its various parts, and also that which flows down the trunk. The latter part reaches the soil and is measurable; the former is evaporated again without reaching the soil. At Nancy arrangements were made for including in the catch of the gauge the part which flows down the trunk. At two stations large gauges were put in; they were of the same size as the tree crown and they embraced the trunk, a collar about which directed the water into the receiver of the gauge. The percentage of catch in the woods was here 92, the largest in stations provided with ordinary gauges. The latter were used at the Bellefontaine station, which was not very distant, and the catch was here 84 per cent. This is larger than for most other reported returns, but the difference between this value and that for Cinq-Franchées may perhaps be

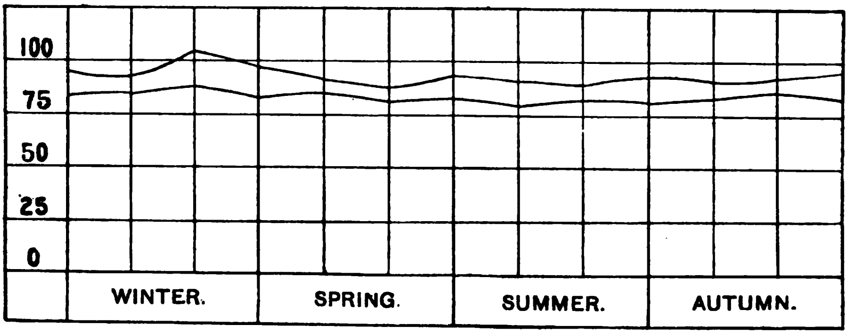


FIG. 56.—Precipitation through trees at Cinq-Franchées and Bellefontaine.

taken as an approximation to the quantity of rainfall which flows down the tree trunk. This would be 8 per cent. These are means from eleven years of observation. Fig. 56 gives the distribution of the percentages through the year. The upper curve is for Cinq-Franchées with its large rain gauge; the lower curve is for Bellefontaine with ordinary gauges. They both show something of the dip for the warm season. At Cinq-Franchées the precipitation under trees for one month (February) is slightly larger than that in open fields.

M. Fautrat's observations include those on precipitation above forests. The rain gauge over the forest was compared with one at the same height and a thousand feet away, over fields. The two pairs of stations were in the forests of Halatte and Ermenonville, and have been already described. The accessible data were, for Halatte, the monthly values for February to July, 1874, and August, 1876, to July, 1877; for Ermenonville, the monthly values from 1875 to July, 1877. These have been changed into inches and condensed into the accompanying table:

	Halatte, deciduous trees.			Ermenonville, Evergreens.		
	W	*O*	*W—O*	*W*	*O*	*W—O*
Winter	7.44	7.35	+0.09	6.11	5.41	+0.70
Spring	6.90	6.54	+0.36	7.47	6.74	+0.73
Summer	7.11	6.69	+0.42	9.25	8.29	+0.96
Autumn	8.88	7.32	+1.56	7.24	7.20	+0.04
Year	30.33	27.90	+2.43	30.07	27.64	+2.43

These results are of so great interest that it is unfortunate that the published series of observations is so short. Rainfall observations, to give satisfactory results, must be derived from a long series of observations. M. Fautrat's observations are very consistent among themselves, however, and the uniformity of signs of *W—O* and the distribution of the values through the season, show that they are not due to accidental limits of heavy rains so arranged as to include one station and exclude the other. According to these observations, the simple precipitation over woods is 9 per cent more than that over open fields in both cases. The amount which reached the ground under the woods was 90 per cent of that over the fields for one year in the case of the deciduous trees, and this gives the large average percentage of 39 for that which was caught by the foliage. For the evergreen trees and the whole series of observations the amount which reached the ground under trees was only 56 per cent of that in the open, giving here 53 per cent as the catch of the trees. The arrangements of rain-gauges by M. Fautrat did not permit the measure of the amount flowing down the trunks. Using the per cent obtained at Cinq-Franchées as the measure of this, we have the following curious and interesting relations between the precipitation over woods, in woods, and outside. The data are percentages of the rain of all outside, in this case at the height of the upper gauge, as that at the lower gauge is not given.

	Fall over woods.	Reached gauge under woods.	Reached ground under woods.	Held by the foliage.
Deciduous trees	1.09	0.70	0.78	0.31
Evergreen trees	1.09	0.56	0.64	0.45
Average of two	1.09	0.63	0.71	0.38

While Fautrat's observations show that there was a higher rainfall over trees in the department of Oise than over comparative stations in the open fields, they do not show that that occurs in Germany or elsewhere, but gives enough of a presumption to that effect to make it worth while to examine the subject more fully. It frequently happens at the German stations that the heaviest rainfalls for the month (which are always noted) are greater under trees than at the field station, but as this could easily be due to heavy local rains it is not especially significant. It is otherwise with the monthly rainfalls. If the monthly

amount under trees is greater than that outside, there is a fair presumption that the rainfall over the trees is persistently heavier, and where this is found for several months, and in the warm season when the precipitation is rain and can not be very long sustained in the foliage, the presumption becomes very much stronger. There were a good many cases in the two hundred years of observation at the German stations when the monthly catch under woods was greater than in the open fields. I will take a few of the most interesting, for the warm season:

Carlsberg, May, 1881 (1.24), and September (1.11); also September, 1885 (1.20), June, 1887 (1.20), and May, 1888 (1.14); Schoo, May to September, 1886 (1.05, 1.00; 1.04, 1.40, 1.40).

These are both stations among evergreens, and the summer reduction of the catch under trees for this season, for the German stations, is .26 per cent. If this is added to the above they become—

For Carlsberg	1.50, 1.37, 1.46, 1.46, 1.40
For Schoo	1.31, 1.26, 1.30, 1.66, 1.66

and it appears that the monthly fall in the woods may be from a fourth to two-thirds more than in adjacent fields. If instead of the .26 per cent of the German service, the .45 per cent found by Fautrat, by actual measurement, as the difference in rainfall above and below evergreens, be added, these values become .19 per cent greater, and the rainfall observations at the forest stations generally become larger than those in open fields.

But Fautrat's .31 per cent for deciduous trees and .45 per cent for evergreens are the results of brief series of observations at only two stations and can not be extended to the results of observations at other stations without uncertainty.

They afford, however, some grounds for the presumption that rainfall is heavier over woods, and it is not hard to find reasons why it should be. But it is most satisfactory to wait until the fact has been proven beyond a doubt, and in the lack of sufficient observations on this point lies the chief and most important gap in forest meteorological work. For the completion of the theory of the action of forests on climate exact observations are needed above trees at many stations and for long series of years, and the most important data to be obtained are those relating to precipitation. The rainfall caught under trees is of minor importance—far subordinate to the amount caught above trees.

PRECIPITATION OVER WOODED AND TREELESS DISTRICTS.

This branch of the forest meteorological problem is the most important of all, has been most discussed, and the discussion has resulted in all shades of opinion, from those absurdly favorable to trees to those utterly adverse. Direct comparison of observations is here not possible, or at least comparable observations have not been carried on, and, as in the case of temperatures over wooded and treeless districts, there is always occasion for doubt whether the differences found at the selected different stations are not due to other things than the presence or absence of forests. The difficulty is, in fact, greater here than in the case of temperatures, because the rainfall is especially sensitive to all sorts of conditions and surroundings, and is also apparently very capricious (changing from month to month or year to year by large amounts and without any discoverable cause). In addition to all this, when a difference of rainfall corresponding to a difference of forest conditions has been found, there is still occasion for doubt as to which is cause and which effect. There is every reason to believe that with increased rainfall, other things being favorable, there will be an increased growth of trees.

The facts at hand do not prove, with entire conviction, that forests increase the rainfall. The historical method is lacking generally in the character of the data for the beginning of the comparison. Besides, where a change of rainfall is actually shown to be coincident with a change in the forest growth it is not entirely certain that the former is due to the latter; it may be due to what are called secular changes of the rainfall, the reasons for which lie beyond our knowledge. The geographical method is not entirely satisfactory, for the reasons already mentioned. The entirely convincing method depends on observations above forests and with systems of radial stations as proposed by Dr. Lorenz-Liburnau, and from these there is not yet a sufficient amount of published results.

It will be of interest, however, to see what is the character of the geographical method so far as it relies on purely meteorological facts.

In 1866–'68 M. Becquerel took a series of observations of rainfall at five stations, at Montargis and Chatillon-sur-Loing, and their vicinity. They are in the department of Loiret, 50 to 75 miles (80–121 kilom.) south of Paris, and contained within a range of 25 or 30 miles (40–48 kilom.) of a country with fields and woods interspersed. His observations gave results as follows:

Station.	Condition.	For 1866.	For 1866–'68.	
		Inches.	*Inches.*	*Mm.*
La Jacqueminière	Wooded	33.30	27.10	688
La Salvionnière	Wooded	32.51	27.09	688
Le Charme	Wooded	31.09	(27.08)	687
Chatillon	Open	24.38	26.25	666
Montargis	Open	24.16	26.94	684

At the end of the first year's observations M. Becquerel calls attention to the larger amount of rainfall at the more wooded stations; at the end of three years, however, he practically recalls this mild suggestion. The observations were taken for two years only at Le Charme and were corrected to make a mean corresponding to that for the three years at the other stations. M. Becquerel also examined the relations of rainfalls to forests in Denmark, but the results were somewhat ambiguous.

The observations made near Nancy were arranged in such a way that some conclusions could be drawn as to the relative rainfall among forests and in open country.

Cinq-Franchées was in the midst of the large wooded plateau called the forest of La Haye, composed of deciduous trees about forty years old.

The field station was in an open space of 10 or more acres, in which was the house of the forester. It was five miles southwest of Nancy. Bellefontaine was on the edge of the forest, about four miles northwest of Nancy. The field station was uncultivated land, devoted to nurseries. It was in the bottom of a valley running northwest and southeast. Six miles northeast of Nancy was the station of Amance, near the summit of a hill, and surrounded by cultivated lands, not entirely treeless, but devoid of forests. Observations were begun later at the agricultural station near Nancy. It was in the open fields about eleven miles from the forest of La Haye. There are only seven years of observations from this station, but eleven from the others. The mean annual precipitation at these stations is given in the accompany ing table:

Station.	Condition.	Altitude.	Mean of seven years.	Mean of eleven years.
		Feet.	*Inches.*	*Inches.*
Cinq-Franchées	Forest	1,247	32.5	31.5
Bellefontaine	Forest	787	31.8	30.7
Amance	Open	1,247	25.5	25.7
Nancy	Open	712	30.4	....

The stations at Cinq-Franchées and Amance are as comparable as stations can be made, and the forest precipitation proves to be about 7 inches greater than that of the open fields. Bellefontaine, on the edge of the forest, has an appreciably greater precipitation than Nancy. These stations were all under one direction, and their results may be considered as significant, especially as to the first and third, which are at the same elevation. The position of the second is unfortunately of such a character that its rainfall might be very sensibly affected.

The rainfall at parallel pairs of field stations has been determined by a series of careful observations. These stations are always near

forests, and it will be of interest to compare their results with those given for extensive regions near them but without forests. Such a comparison is made in Dr. Lorey's handbook of forestry; in reproducing it the units of measurement are changed to feet and inches. The stations are arranged in the order of their elevation above the sea. The averages for the larger regions are those published by Dove in 1871.

Field station.			Compared with average over open regions.		
Name.	Elevation.	Mean annual precipitation.	Name.	Mean annual precipitation.	Surplus over woods.
	Feet.	*Inches.*		*Inches.*	*Inches.*
Schoo	10	28.4	North Sea coast	27.5	+ 0.5
Eberswalde	77	21.9	Brandenburg	21.8	+ 0.1
Fritzen	98	25.6	East Prussia	24.1	+ 1.5
Hadersleben	112	30.1	Baltic coast	26.0	+ 4.1
Lintzel	312	23.3	Hanover	26.9	− 3.6
Kurwien	407	24.5	East Prussia	24.1	+ 0.4
Marienthal	469	22.5	Thüringen and Saxon Provinces	23.2	− 0.7
Hagenau	500	31.6	Alsace-Lorraine	30.4	+ 1.2
Neumath	1,159	32.3	do	30.4	+ 1.9
Friedrichsrode	1,158	26.5	Thüringen and Saxon Provinces	23.2	+ 3.3
Lahnhof	1,975	44.2	Westphalia	30.7	+14.5
Hollerath	2,005	38.3	Rhine country	25.6	+12.7
Schneidefeld	2,230	50.2	Thüringen and Saxon Provinces	23.2	+27.0
Carlsberg	2,400	38.9	Silisian Mountains	27.2	+11.5
Sonnenberg	2,549	55.5	Harz	36.4	+19.1
Melkerei	3,071	69.9	Alsace-Lorraine	30.4	+39.5

It seems from this that, where the results at the stations near forests are compared with the general results in the section of country in which the station is situated, the forest station usually shows more rainfall. Lintzel is exceptional, because near young trees on an exposed moor.*

* In regard to this station Dr. Müttrich has lately published an interesting account which should correct the above result, and would go far to show a noticeable influence of the growing forest cover upon rainfall.

This station, situated in the Luneburg heath, was begun to be planted to forest in 1877, at the rate at first of 1,000 to 1,500 acres per year, afterwards more slowly, and by this time over 8,000 acres have been planted to forest in that locality. Around the meteorological station a young forest of 10 to 12 years old, of pine and oak, has grown up. The station is placed in an open field of about 75 acres extent surrounded by the forest growth. The change of conditions immediately around the station Lintzel, making Lintzel central for an area of about 25 square miles, is represented as follows:

Before reforestation:	After reforestation:
12 per cent field, meadow, etc.	10 per cent field, meadow, and water.
85 per cent heath.	10 per cent heath, roads and openings.
3 per cent old forest.	80 per cent of forest.

There are now regular meteorological observations for nine years on hand.

The rainfall observations are compared with those from stations outside of the forest conditions, but near enough to Lintzel to be available for comparison in the

There are, however, considerable variations in the elevations of the stations employed to get the average values given.

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following table; the values having in both cases been equalized to eliminate irregularities by calculating the means of each three to four years by the formula

$$\frac{2a+b}{3},\ \frac{a+2b+c}{4},\ \frac{b+2c+d}{4},\ \text{etc.}$$

TABLE 1.—*Equalized values of precipitation, in millimeters.*

Year.	Lintzel.	Bremen.	Lintzel.	Hamburg	Lintzel.	Oslebshausen.	Luneburg.	Gardelegen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1882	514.7	797.6	514.7	643.7	514.7	673.9	561.0	534.7
1883	550.5	798.8	550.5	650.9	550.5	675.6	575.1	545.0
1884	639.3	821.2	639.3	681.5	639.3	676.3	619.0	599.3
1885	620.3	756.2	620.3	650.2	620.3	579.3	588.7	567.9
1886	533.3	636.0	533.3	570.9	533.3	496.1	512.4	467.1
1887	546.3	568.0	546.3	580.1	546.3	521.2	530.2	454.4
1888	650.0	608.5	650.0	706.1	606.3	578.2	625.2	504.9
1889	705.0	665.9	736.2	781.4				
1890	668.0	657.3						

From this table the percentage of rainfall in Lintzel, as related to the rainfall of each of the other stations, is calculated as follows:

TABLE 2.—*Rainfall at Lintzel calculated as percentage of rainfall at certain places.*

Year.	Bremen.	Hamburg.	Oslebshausen.	Luneburg.	Gardelegen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1882	64.5	80.0	76.4	91.7	96.3
1883	68.7	84.6	81.5	95.7	101.0
1884	77.8	93.8	94.5	103.3	106.7
1885	82.0	95.4	107.1	105.4	109.2
1886	83.9	93.4	107.5	104.1	114.2
1887	96.2	94.2	104.8	103.0	120.2
1888	106.8	92.1	104.9	93.8	120.1
1889	105.9	94.2			
1890	101.6				

The author concludes that if the increasing reforestation at Lintzel had no influence on the amount of rainfall, the figures for Lintzel should have been nearly in constant proportion to those for the other stations, while from the percentage table it appears that with reference to neighboring stations the precipitation at Lintzel has increased with the increasing forest growth. The differences in the last years are not so apparent, because the values could not be properly equalized. It is, however, undoubtedly proved that at the beginning of observations the rainfall at Lintzel was less than at any of the neighboring stations and that subsequently it increased from year to year, until it was in excess of the other stations, except at Hamburg.

Comparing the rainfall at Lintzel with that of the other stations, and calculating it as percentage of the mean rainfall of the latter, the following series is obtained:

	Per cent.
1882	81.8
1883	86.3
1884	95.2
1885	99.8
1886	100.6
1887	103.7
1888	103.9

This constant increase, going hand in hand with the increase of forest cover in extent and height, leaves hardly any doubt as to the close relation of the two conditions.—B. E. F.

To eliminate this, compare the stations mentioned with other German stations of about the same elevation. For this purpose the rainfalls at 192 stations given by Dr. van Bebber were used, and these and the previous ones were combined for each hundred meters.

Elevations.	Meters 1-100.	100-200.	300-400.	600-700.	100-800.	100-1000.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Average from forest field station	25.8	26.2	29.4	42.9	55.5	69.9
Average from Van Bebber	25.5	22.9	27.4	36.0	38.6	38.0
Surplus for forests	+ 0.3	+ 3.3	+ 2.0	+ 6.9	+16.9	+31.9
Percentage of surplus	1.0	14.0	7.0	19.0	44.0	84.0

This comparison throws some light not only on the amount of surplus over woods, but on the distribution of it. It increases rapidly with the elevation. For 328 feet (99.9 m.) or under, it is but 1 per cent; from this to 1,300 feet (396 m.) it is 7 to 14 per cent; between 1,950 (594 m.) and 2,270 feet (692 m.) it is 19 per cent; between 2,270 (692 m.) and 2,628 feet (801 m.) it is 44 per cent; and above the last the surplus appears to be 84 per cent, or the precipitation over forests is nearly doubled.

It is easy to show that, in general, heavily wooded districts have a high rainfall, as compared with similar districts without forests. This is notably true in India, as shown by Dr. Brandis and others. It is enough to say that the heaviest known rainfall occurs in one of the densest and most extensive known forests, that of the middle and lower Brahmaputra. But in all these cases it is more probable that the forest exists because of the rainfall, rather than *vice versa.* A case which is more favorable to the influence of forests on rainfall is given by Dr. Woeikoff, depending on the rainfall distribution on Java and Celebes. Java has extended and dense forests in the south and in the southwestern interior, while the north coast has been largely deforested. The station Tjilatjap on the south coast is at a distance from mountains. Its annual rainfall is 182.3 inches (4,630 mm.). That for three stations on the north coast (Batavia, Tegal, and Samarang) is 78.4 inches (1,991 mm.) or 43 per cent only. In this region the north side of the islands is the weather side for the northwest monsoons and should have, at least from December to March, more rain than the south side, because this wind descends to reach the latter. As a matter of fact there falls in these months—

At Tjilatjap ....45.7 inches (1,161 mm.)
At the north coast stations ....43.3 inches (1,100 mm.)

or almost as much on the lee side as on the windward, while there should be very much less on the latter.

Celebes, where there is no such deforesting, gives the normal annual values:

Celebes:

Northern peninsula—windward, 110.6 inches (2,809 mm.); lee, 55.1 inches (1,399 mm.)

Southwestern peninsula—windward, 136.2 inches (3,458 mm.); lee, 100.0 inches (2,540 mm.).

West Central Java:

Windward, 78.4 inches (1,991 mm.); lee, 182.3 inches (4,630 mm.)

It appears that in Celebes the windward side has a notably higher rainfall than the lee side, while in Java it is reversed. Is this not due to the relative lack of forest growth on the north side of Java? Where forest growth exists the rainfall is higher, even there. For instance, at Lormadjang, in a densely wooded level area, the annual rainfall is 73.7 inches (1,872 mm.), while at the two nearest stations on the same side it is only 46.9 inches (1,191 mm.).

The literature of the historical treatment of this problem is very great, and the most extreme and absurd opinions can be found registered in it. It usually suffers under the objection, first of imperfect data at the beginning, and always under that of uncertainty as to the cause of any variation of rainfall which may be found.

The argument founded on changes in regions mentioned by ancient writers deserves consideration only to point out its extreme unreliability. The condition of the countries in question at the beginning of the comparison is based on incidental references in the classics which are not only incomplete but which are usually in ambiguous terms. The classical terms for forest have an extensive range of meaning, as will be seen by reference to any classical dictionary, greater than that of our word forest, which is used in law English to designate areas which now have no woods, and in some cases there is no evidence that they ever had any.

Much more trustworthy are the more modern cases which depend on meteorological observations; but in these the earlier observations are not so trustworthy as to give assurance that any differences found are not the result of imperfect observations. The writer endeavored, some years ago, to show that along the parallels of latitude 40° and 42° in the Mississippi Valley the lines of higher rainfall were moving slowly westward with the advance of settlements, but it was abundantly shown that the sparsely scattered earlier observations were quite untrustworthy.

There is one further case, which is quoted by Dr. Brandis, for India. In the part of the central provinces between the Nerbudda River and Nagpur and Rajpur, embracing a part of the Satpura range of mountains, much attention has been paid for several years to the care of the forests, and specially to protection against forest fires. In consequence a large territory, with scattered tree growth or entirely treeless, has

been covered with a dense growth of young trees. Over this region the rainfall has been as follows, at the stations named:

	1875 and before.		1876 to 1885.	Per cent of increase.
	Years.	Mean annual.		
		Inches.	*Inches.*	
Badnur	1867–1875	39.83	47.83	20
Chindwara	1865–1870	41.43	48.48	17
Seoni	1865–1875	52.07	54.76	5
Mandla	1867–1875	53.58	56.32	5
Burha	1867–1875	64.51	71.65	11
Bilaspur	1865–1875	41.85	54.81	21
Rajpur	1866–1875	51.59	54.41	5
Annual average	....	49.27	55.47	13

From the 37-year series of observations at Nagpur, and the 40-year series at Jubbulpore, on the north side of the Satpuras, it appears that the probable error of a 10-year series of observations is 5 per cent. Farther, it appears from the combination of rainfall observations in India that in 1876–1885 the rainfall was 0.66 inch (17 mm.) greater than in 1866–1875.

If one half of the above difference be attributed to error and to a general increase of rainfall, there yet remains an appreciable addition which might be attributed to the growing forest. At least it may be taken as an indication which, combined with the results of observations above trees, makes a good presumption that a forest does actually increase the rainfall by an appreciable percentage. It should be noted that the forest fires practically ceased before 1865, and that at that date the forest growth had been fairly started over small surfaces. By 1875 it had extended over a surface of about 1,000 square miles.*

*NOTE.—It seems appropriate in this connection to quote the following extract from Mr. Fernow's annual report for 1888:

"Blanford, who has recorded these observations in the above manner, adds that these results, of themselves, are not proof absolute for the influence of forest preservation, since possibly the earlier observations were less reliable than the later, but that these observations may be considered as addenda to the accumulating signs of the existence of such influence on rainfall.

"But even this method, which would class with my retail methods, although seemingly simple, before it can be admitted as conclusive, must, as the writer says, be guarded by those special precautions which are demanded by strict scientific inquiry.

"The above figures were hailed with satisfaction by those who are bound to prove by statistics the forest influence on rainfall.

"Unfortunately, as this report goes to press, their value is entirely vitiated by the following statements made in the Indian Forester, January, 1889, which again admonishes us to be careful in placing too much weight on statistics.

"Mr. Blanford, in order to assure himself of the value of the rainfall returns he employed in the discussion of the Central Provinces, wrote to the chief commissioner on the subject, to which the reply was received that 'the chief commissioner fears that these records of rainfall previous to 1883 can not be accepted as altogether reliable.' The commisioner explains the reasons why the records appear unreliable, and

The balance of waters in forest regions can not be made up until there is greater certainty as to the precipitation over forests.

It has already been shown that the forest preserves a considerable proportion of the waters which reach its soil. This is due, for the most part, to its lessened evaporation, and this alone would account for the moisture of forest soil, for the preservation of bodies of water, and of perennial springs in regions of dense forest. If the forest also condenses more moisture from the air, then the same effects would follow in regions more lightly clothed with woods.

FORESTS, WIND, AND STORMS.

There remain a few points of more or less interest, which have received considerable discussion, but have not been the object of systematic observation. Among these is the windbreak effect of the forests. Like any other elevation above the surface, the forest protects from the wind objects which are in its lee, and, over a very much smaller area, those which are on its windward side. The outlines of the protected area are defined by the outlines of a snowbank before and behind a fence. A section is given in the accompanying figure, where *A B* is the fence, *W* the snow to windward of it, *L* that to leeward. The windward protection is so small as not to deserve discussion in this connection. As to the leeward protection, the chief point of interest is the length of the line *B C* as compared with the height *A B*, or

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adds: 'Hence one result of the unsystematic registration of the rainfall in the Central Provinces is to postpone the decision of the influence of forests on rainfall in that area for another twenty years. It is only one of the many cases of the worthlessness of unsystematic observations.'"

It is of interest also to note the following from the same source:

"In the following extract from the same report Mr. Eliot refers to the observations recently undertaken in the forests of the Saharunpoor district. For the reader unacquainted with the Western Himalayas it is necessary to explain that a *rao* is a water course issuing from the hills, and having, generally, a broad, shallow bed, which consists mainly of bowlders and shingle, and is therefore quite dry or almost dry, except after a continuous heavy shower. Mr. Eliot has not mentioned that in each *rao* levels are accurately taken every year along one and the same line, in order to note the changes that may occur in the section of the *rao* in consequence of the fire conservancy of the entire basin above.

"A different method has been introduced in the Saharunpoor forest division. Twelve representative *raos*, between the Ganges and Jumna rivers, have been selected for purposes of observation by the inspector-general of forests and conservator of the school circle, and in each forest chowki a rain guage is suitably placed. Five of them are located in the forest of Sakrauda, which is neither closed to grazing nor protected from fire. The rainfall measurements will be made by the forest guards, and the returns submitted to the meteorological department for critical examination. These observations will probably give a valuable series of data for testing the effect of different forest conditions in modifying the amount of rainfall, and hence also probably throw some light on the general question of the influence of afforestation on rainfall."

the ratio of the width of the protected strip to the height of the obstruction. M. Becquerel says that in the Rhone Valley a hedge 2 meters (6 feet) high will protect delicate garden plants to a distance of 22 meters (70 feet). This is a ratio of 1 to 11, and this ratio is about that given in the following cases gleaned from Dr. Hough's report on forestry for 1887. Judge Whiting, of Iowa, is quoted as saying that this protection, "with almost mathematical precision, amounts to 1 rod on the ground to each foot of height" of the protecting trees. This is a ratio of 10 to 165. Mr. Barnard, of Pawnee County, Nebraska, stated that a windbreak will protect an orchard a rod for every foot in height, but Prof. Thomson wanted trees 25 feet high for every 10 rods of protection. The two latter cases relate to orchards which rise 10 or 20 feet above the surface. A probable estimate is that the forest creates a calm area on its leeward side, which is, at the ground, ten to fifteen times as wide as the forest is high. The protected area has the same relations

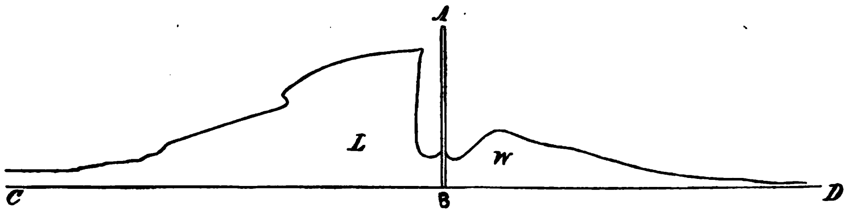


FIG. 57.—Snowbank before and behind a fence.

to temperature that a glade has. The air is relatively stagnant, and temperatures rise higher in the direct sun's rays and fall lower on clear nights. Evaporation is also somewhat decreased in this space, but its chief advantage is found in the protection from injurious cold or dry winds. The rough surface of the forest must also decrease the velocity of the wind, with the result of affecting the character of a storm which passes over it, especially if the storm be small or local. Dr. Waldo has given two interesting cases where the results are due undoubtedly to several causes, one being the retarding effect on the wind of a surface of city buildings. At both New York and Boston there are three meteorological stations, one out in the harbor, the second in the city, the third fairly beyond the city (Central Park and Cambridge). The mean velocities at these three stations in order are, in percentages:

	Harbor.	City.	Suburbs.
New York	1.00	0.67	0.37
Boston	1.00	0.67	0.33

The reduction of the velocities as one goes inland through the city is remarkable, and something similiar may be expected for a wind passing over a forest.

As the interior air of the forest is generally cooler, in the warm season, than the air outside, it must be heavier, and the difference of temperature must be often so great that the heavier air will overcome the

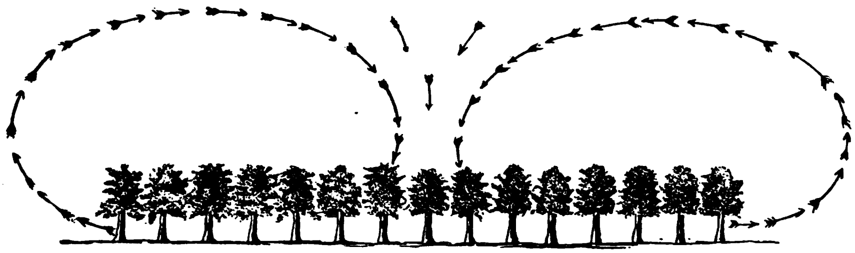


FIG. 58.—Forest circulation.

obstacles to its flow and gradually pour out near the ground. Its place will be taken by the air above which will settle, and thus there may be set up a forest circulation, as represented in the figure (Fig. 58)

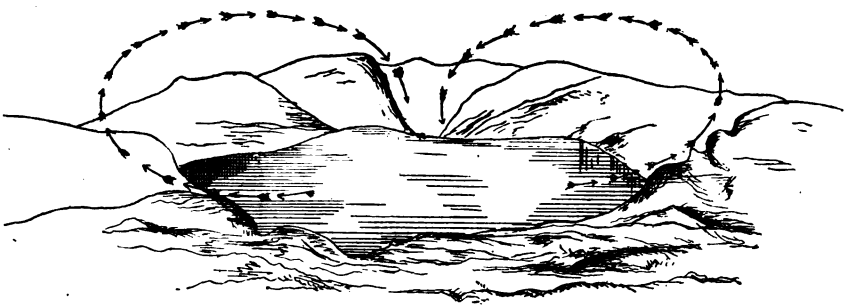


FIG. 59.—Day circulation.

exactly corresponding to such a system of winds as is found in land or sea breezes, or may be found over a lake at night.

During clear nights the forest air is generally warmer than that out-

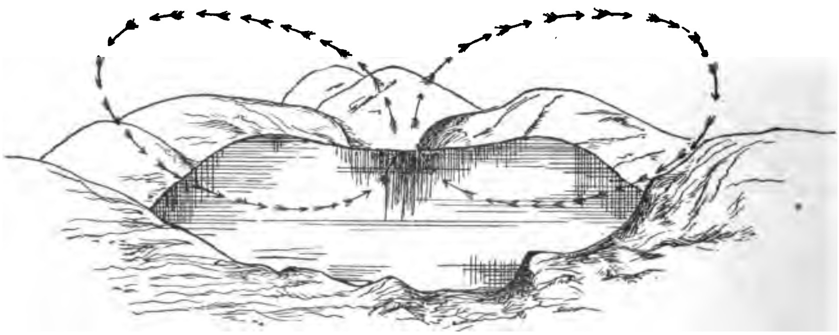


FIG. 60.—Night circulation.

side. When this happens a reverse circulation might be set up. This circulation must be slow, and though somewhat enlarged on by writers on the subject seems never to have been directly observed.

INFLUENCE OF FORESTS ON FOGS AND CLOUDS.

The influence of forests on fogs and clouds has been frequently mentioned, and observed in single cases. The fog seems to linger in the woods after it has cleared off elsewhere. Trees also act as condensers,* as gatherers of dew, hoarfrost, and ice, and the latter phenomenon is especially remarkable in the so-called ice-storms, where the accumulation is so great as to overload and break the larger limbs and branches. In these cases, however, the tree acts like inorganic bodies. This is illustrated by a celebrated case on the island of Ascension, the details of which are due to Prof. Cleveland Abbe, who in 1890 personally inspected the phenomenon. This case is especially worth quoting because its records have been so badly understood. The principal water supply for the garrison of this naval station is gathered several miles away, at the summit of Green Mountain, the upper part of which has always been green with verdure since the island was discovered; almost all of this water comes from slight showers and steady dripping of trees enveloped in cloud-fog on the windward side of the mountain. Every exposed object contributes its drip; these do not condense the water, they simply collect it mechanically after it has been condensed in the uprising cooling air. Whatever fog-drops are not thus collected sweep on over the mountain and quickly evaporate again. Thirty years ago or more efforts were made to plant a few trees in the arid spot at the garrison landing; none survived, but some few new shrubs were added to the flora of the mountain top; extensive additions were also made to the mountain reservoirs and drip collectors and pipes of the aqueduct system. The few artificial scrubby plants have had no influence whatever in increasing the water supply.

INFLUENCE OF FORESTS ON HAILSTORMS AND BLIZZARDS.

M. Becquerel found, by a careful study of the destructive hailstorms in some of the departments of Central France, that these storms show a marked disinclination to enter forests. On the maps of the departments studied by him he has marked the severe storms by spots of color. A glance at the maps shows how persistently the colors keep outside the forests, especially the larger ones. To controvert these views, cases of hailstorms in forests have frequently been pointed out, but the question is not of absolute but of relative immunity of forests from severe hailstorms, and that these cases do not affect. The subject remains where it was left by M. Becquerel. It still appears proven that in Central France hailstorms avoid forests.

Many other relations of forests to storms have been suspected and advocated. For instance, that the storm precipitation is more intense

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* See p. 124 of this bulletin.

over prairies, that the heavy windstorms—such as blizzards—do not long survive the traverse across a forest area, etc., but these relations still remain in the condition of hypotheses only. Forests also have broad and important relations to the flow of water on the surface, to the protection of movable soils, and to many other features of practical importance. These are matters for discussion by engineers rather than by meteorologists.

III.—RELATION OF FORESTS TO WATER SUPPLIES.

By B. E. Fernow.

THE TOTAL WATER SUPPLY.

The water capital of the earth consists of two parts, the fixed capital and the circulating capital. The first is represented not only in the waters on the earth, but also by the amount of water which remains suspended in the atmosphere, being part of the original atmospheric water masses which, after the rest had fallen to the cooled earth, remained suspended and is never precipitated.

The circulating water capital is that part which is evaporated from water surfaces, from the soil, from vegetation, and which, after having temporarily been held by the atmosphere in quantities locally varying according to the variations in temperature, is returned again to the earth by precipitation in rain, snow, and dew. There it is evaporated again, either immediately or after having percolated through the soil and been retained for a shorter or longer time before being returned to the surface, or, without such percolation, it runs through open channels to the rivers and seas, continually returning in part into the atmosphere by evaporation. Practically, then, the total amount of water capital remains constant; only one part of it—the circulating capital—changes in varying quantities its location, and is of interest to us more with reference to its local distribution and the channels by which it becomes available for human use and vegetation than with reference to its practically unchanged total quantity.

As to the amount of this circulating water capital we have very imperfect knowledge; in many cases an approximate estimate of the amount circulating in any given area can not be satisfactorily made with the means of measurement at command, for often the precipitation is so unevenly distributed, as in the case of local thunderstorms, that two rain gauges a short distance apart collect varying amounts; hence a record from one gauge alone would give a very erroneous idea of the rainfall over the entire area. Furthermore, when improperly situated or exposed to high winds a rain gauge may furnish quite inaccurate records, and in the majority of cases the amounts collected by the gauge will be insufficient. (See Prof. Abbe's paper in this bulletin.)

A singular illustration of these errors is presented in a hydrographic investigation of the river Rhone and its watershed. While the amount of annual discharge of the river corresponds to a rainfall of 44 inches over the watershed, the rainfall records themselves for a certain period gave a precipitation of only 27.6 inches. Even the close estimate of the waters of the upper Elbe, according to which they drain one-fourth of the total rainfall, calculated by the ingenious methods of Prof. Studnicka, does not inspire confidence. The attempts of the U. S. Weather Bureau to relate river stages to rainfall measurements have also so far failed to yield satisfactory results. Again, much of the moisture which is condensed and precipitated in dews escapes our observation, or at least our measurements, entirely; * this is, however, so small a quantity that it may be neglected in its relation to the total precipitation.

Late investigations have brought convincing proof not only that the amount of dew is much smaller than was supposed, but also that the larger part of the deposit is derived from the moisture of the soil and not from that of the atmosphere; that, therefore, dew formation in many cases can not be considered an additional water supply, but rather an element of dissipation. While G. Dines calculated the annual amount of dew at best equivalent to 38 mm. rainfall as against 127 mm. as formerly estimated for England, Wollny, upon careful measurements, calculated it for Munich at 28 to 32 mm. or less than 3½ per cent of the total rainfall. The theories regarding dew formation, according to which the moisture is deposited from the atmosphere in a manner corresponding to the familiar phenomenon on the ice pitcher, which was first antagonized in 1833 by Gerster and later by others, among whom our countryman, Stockbridge, seem in part at least incomplete and needing revision.

The distribution of the circulating water capital is influenced by various agencies. The main factor which sets the capital afloat is the sun, which, by its heat and the air currents caused by it, produces the evaporation which fills the atmosphere with vapor. Anything, therefore, that influences the intensity of insolation or obstructs the passage of winds must influence the local distribution of the water capital, and hence a forest cover, which withdraws a portion of the soil from the

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*A few experiments on condensation of aqueous vapor made by L. Hampel with forest tree leaves are of interest:

	Centigrams.
Austrian pine (4 needles) condensed per day in the average	4.84
Linden (one leaf) condensed per day in the average	24.40
Oak (one leaf) condensed per day in the average	25.56
Spruce (a branchlet) condensed per day in the average	9.80

The linden, of which one leaf condensed 24.40 centigrams of dew, had 1,763 leaves. It would, therefore, if all leaves had done the same, which is to be sure not the case, have condensed 430 grams (nearly 1 pound).

On grass the amount of dew per year was found by G. Dines to be 27 millimeters; *i. e.*, if collected an amount corresponding to 27 millimeters (over 1 inch) height of water would have resulted.

influence of sun and wind, must have an influence, however small, on the local water conditions, which may or may not become appreciable in human economy.

The question of forest influence on water supplies may be considered under three heads, namely: (1) Influence upon precipitation or upon the distribution of atmospheric water; (2) influence upon the disposal and conservation of available water supplies; (3) influence upon the "run-off" or the distribution of terrestrial waters.

INFLUENCE OF FORESTS UPON PRECIPITATION.

The question whether forest cover has or has not an influence upon the quantity of rain or snow that will fall over a given area is discussed at length on pp. 111–117 of this bulletin and also upon additional data in my annual report for 1888. It may suffice, therefore, to state only the conclusions which may fairly be drawn from our present knowledge and experience:

(1) Finding the air strata above forest stations moister and cooler, although only slightly so, than over field stations, we would infer that the tendency to condensation over wooded areas might be greater than over open fields. Experience and measurements seem to sustain this reasoning.

(2) These cooler and relatively as well as absolutely moister air strata carried away by air currents must modify conditions near the forest and possibly increase in its neighborhood also the tendency to formation of dew and to other precipitation under certain conditions.

(3) While the forest may not everywhere increase precipitation over its own area and near it, yet the presumption is that large systems of forest growth over extensive areas alternating with open fields may establish sufficient differences in temperature and moisture conditions and in air currents to modify, if not in quantity yet in timely and local distribution, the fall.

(4) It must not be overlooked that the extent, density, height, and composition, and relative position of the forest in making it a climatic factor are important conditions, and furthermore that there are certain rain conditions prevailing in climatic zones (rainy or rain-poor localities, with periodical, seasonal, or irregular rains) which are due to cosmic influences and can not be altered, yet may be locally modified by forest cover. Hence experience in one climatic zone or under one set of conditions can not be utilized for deductions in another.

(5) Altogether the question of appreciable forest influence upon precipitation must be considered as still unsolved, with some indications, however, of its existence under certain climatic and topographical conditions in the temperate zone, especially toward the end of winter and beginning of spring.

As one of the most striking examples of an increase of precipitation, seemingly due to forest planting, the experience at Lintzel, on the Lüne-

burg heath, may be recalled, where, with a definite increase in forest conditions over an area of 25 square miles, a regular definite increase in rainfall beyond that of neighboring stations to the extent of 22 per cent within six years was observed, and a change from a deficiency to a considerable excess over the rainfall of these other stations.

RESULTS OF OBSERVATIONS NEAR NANCY, FRANCE.

The following observations were made at two stations in the neighborhood of Nancy, France. The instruments and their disposition were identical at the different stations. A is a forest station; C, a field station; B is on the verge of the forest and at a lower level. The following table gives the amount of rainfall in centimeters for the seven years 1867, 1868, and 1872, 1873, 1874, 1875, and 1876:

Time of observation.	Station A (forest glade), 380 meters.	Station B (forest verge), 240 meters.	Station C (field), 380 meters.
	Cm.	*Cm.*	*Cm.*
February to April	15.9	16.2	14.9
May to July	18.9	17.1	16.6
August to October	20.7	17.2	15.7
November to January	21.2	18.8	17.7
Year	76.7	69.3	64.9

RESULTS OBTAINED IN BOHEMIA.

It may also be appropriate here to recall the method by which Dr. Studnicka tried to establish the influence of forest areas upon the distribution of rainfall, an account of which I reproduce here from my report for 1888:

The latest, most valuable scientific work which has been done to decide the important but difficult question of the influence of forests on precipitation is the work of Dr. F. J. Studnicka, professor of mathematics at the University of Prague, published under the title, "Basis for a Hyetography of Bohemia," in which the results of many years of observation at seven hundred ombrometric stations are embodied, critically sifted, and scientifically considered. The author employs a wholesale method which is quite novel, complying with Woeikoff's idea that it is necessary to reduce the observed data to a common basis for comparison. To understand the significance of these observations an inspection of the map of Bohemia will be desirable, which shows it to be a basin surrounded on all sides by high mountains.

The work of ombrometric observations, although begun in Bohemia during the last century, was newly organized in 1879 or 1880, when a systematic net of ombrometric stations was instituted, and in 1885 and 1886 it was extended to over seven hundred stations, for the purpose of obtaining accurate data of the quantity and distribution of precipitation over the Kingdom. Uniform ombrometers were used and very carefully placed. As at present organized, there is one station for every 75 square kilometers (about 30 square miles). No other country, I believe, can boast such a service. Although the time of observation at most stations has been short, and the averages would have been more accurately represented by an extension of observations for ten to twelve years, yet the last four years of observations, for which

all stations furnish data, according to the author, represent two extreme and two average years, and are therefore quite useful.

The very large mass of material permitted a sifting out of doubtful observations without impairing the number of available ones for the construction of a rain map of Bohemia, showing by isohyetal lines seven rain-belts or zones; the zones are arranged so that the lowest shows less than 500 mm. rainfall, the three following differ by 100 mm. each, the fifth and sixth by 200 mm., and the seventh by 300 mm.; the last showing, therefore, a rainfall of 1,200 to 1,500 mm.

The central basin divides itself into two halves by a line from north to south, running somewhat east of the middle Moldau, crossing the Elbe near the mouth of the Iser, and following the latter river; the western half showing the smaller amount of precipitation, namely, 500 to 600 mm.; the eastern with 600 to 700 mm., continuing in a small belt along the foot of the Erzgebirge and the Boehmerwald encircling the first zone.

The other isohyetal lines do not embrace continuous areas, but follow in small belts the trend of the mountains. The largest amounts of precipitation are found in belts or islands in the higher altitudes of the mountains which surround this great basin. The continuity of the zones is much interrupted, so that it would be difficult to describe them without a map.

The maximum of rainfall, with over 1,200 mm., is observed in the south, near the sources of the Moldau and Motawa; in the north, near the sources of the Elbe, Iser, and Aupa, on the range of the Schneekoppe. In regard to the distribution through the months, the experience has been confirmed that with increasing absolute height the winter precipitation increases in greater proportion than the summer precipitation, while those of spring and autumn are nearly equal.

Sufficient material was on hand from which to calculate the influence of altitude on the increase of precipitations, although for altitudes above 500 m. the material is not considered sufficiently reliable. Yet the general law is well shown that with the altitude the quantities of precipitation increase in a retarded progression. This progression is calculated by forming altitude zones from 100 to 1000 m., grouping the stations in each, calculating the mean elevation and also the mean annual precipitation as observed for each class; then by dividing the difference of precipitation in the neighboring two zones by the difference of altitude the amount of precipitation which corresponds to each 1 m. elevation within that class is found. With this figure the average amount of rainfall which theoretically belongs to each station according to its absolute elevation can be approximated by adding to or subtracting from the mean precipitations of the class as many times this amount as the actual altitude differs from the mean.

An example will make this clear: Tetschen, for instance, is situated 150 m. above sea level. According to the table the average elevation of thirteen stations of the lowest zone, to which Tetschen belongs, is 182 m., with an average precipitation of 506 mm. Now, Tetschen has an elevation 32 m. lower than the average; its normal rainfall should therefore be $32 \times 0.79 = 25.4$ mm. less than the mean of the class; hence, theoretically, according to its altitude, the quantity of rainfall for Tetschen should be $506 - 25.4 = 480$ mm.; that is 248 mm. less than that actually found in an eight years' average. By using the figures for the two extreme zones and dividing by 100 the mean increase of precipitation for every 100 m. elevation is found to be 69 mm.

And now comes the application of this method to our proposition. The author argues that if the actually observed rainfall differs considerably from the theoretically determined, this is an indication that special agencies are at work. He finds now that of the one hundred and eighty-six stations which he subjects to scrutiny (these offering the longest and most trustworthy observation), forty-eight show a considerable difference between the observed and the theoretically expected rainfall, and he finds also that these stations are situated in the most densely wooded portions of the Kingdom.

The increased rainfall on the forty-eight stations is so considerable that a sufficient quantity may without losing significance be ascribed to other local causes, as, for instance, height and form of a mountain range in front or back, etc. Besides, the greater amounts of rainfall at these stations have been used in calculating the averages for the altitude zones, magnifying, therefore, these averages so that the actually observed one appears really smaller than if the quantities from deforested and forest areas are compared.

Expressed in percentages of the height of precipitation, an increased rainfall is shown for several localities in very large quantities, which will allow considerable reductions for other influences without losing their significance for the main proposition. Especially important appears the fact relating to two stations near the rain minimum, which also shows this influence of the forest.

Lastly, as a matter of interest I may state that the water balance is drawn for the whole Kingdom, which is of special value, because the political boundaries coincide with those of the upper Elbe watershed; therefore it is easy to determine how much of the yearly rainfall is removed by the natural water courses. According to the calculations made for the various zones by addition, the total precipitation upon the area of 51,955.98 square kilometers (about 20,000, square miles) of the Kingdom is found to be 35,398,670 cubic meters, of which the Elbe carries about one-fourth, or 8,849,667 c. m., to the sea. This figure represents a mean rainfall for the whole country of 681 mm., while the mean of observation is 693 mm.

RESULTS OF OBSERVATIONS IN INDIA AND BRAZIL.

The following interesting observations show the remarkable influence of forest areas in tropical and subtropical countries (Annual Report, 1889). Conditions in India are exhibited in the following table:

Influence of forest areas on rainfall in India.

Name of place.	Distance from the sea.	Mean temperature.				Extreme maxima.*	Relative humidity.				Precipitation.			
		April.	May.	June.	July.		April.	May.	June.	July.	April.	May.	June.	July.
Woodless country:	*Kms.*										*Cms.*	*Cms.*	*Cms.*	*Cms.*
Lucknow	847	30.1	33.3	33.1	30.4	45.8	30	36	54	74	0.5	1.8	13.3	39.4
Benares	590	30.2	33.2	32.8	29.7	45.0	41	60	81	82	0.5	1.3	12.9	32.4
Patna	445	30.3	31.4	31.4	29.2	44.6	....	....	....	....	1.0	2.5	16.9	27.8
Barhampur	270	29.6	30.1	29.2	28.7	44.1	52	60	75	79	5.6	10.1	24.2	25.8
Wooded country:														
Goalpara	427	25.2	25.9	26.9	27.7	35.1	66	77	85	84	14.8	33.6	64.3	50.0
Sibsagar	555	23.5	25.3	28.2	28.5	35.6	81	82	83	83	25.9	30.8	39.5	40.6

* Mean of two years.

A glance at this table will show *that the presence of woods has a far greater influence in mitigating the temperature during the hot and dry months of April and May than the proximity of the sea. The same is true of the relative humidity,* especially at Sibsagar, *i. e., in the middle of the forests. Most striking is the effect of the presence of woods in the diminution of the extreme maxima. The greater or less proximity of the sea has but little effect, but as soon as we reach the wooded region the extreme maximum falls 9 degrees.* Thus in 1875 the maximum thermometer did not rise above 35.3 degrees at Goalpara, while at Lucknow there was not a single day from March 14 to June 22 on which a higher temperature had not been observed. The great humidity of the air even during the hot and dry months of April and May is the cause why, in the forests, the rains begin early in March and gradually increase in intensity until

June or July, while in the woodless plains of the Ganges the amount of rainfall suddenly increases from May to June or from June to July.

The Amazon basin.—At the present time there are in the basin of the Amazon four stations where observations are made; this river basin is the most extensive forest region on the earth. The middle and upper portion of the course of the Amazon is over 1,000 kilometers distant from the Atlantic Ocean, while it is separated by mountains from the Pacific. Were it not for the forests we ought to expect, at this distance from the sea and so near the equator, very high temperatures and great dryness. The following table shows the results of the observations:

Difference of temperatures of four stations in the basin of the Amazon.

Name of station.	Height above sea.	South latitude.	Distance from Atlantic.	Temperature. Annual mean.	Temperature. Mean of hottest month.	Temperature. Extreme maxima.	Relative humidity for the year.
	Meters.	*Degrees.*	*Kiloms.*				
Para*	....	1½	100	27.0	27.7	....	....
Manaos	37	3	1,150	*26.1	27.0	*35.7	*80
Iquitos	95	3½	2,100	24.8	25.7	32.4	83
Pernambuco*	3½	8	0	25.7	27.1	31.7	72
San Antonio on Madeira River	....	9	1,750	26.0	27.0	....	....

* Ten months, from October to July.
† Pernambuco does not belong to the Amazon basin; its means are only given for comparison with those of San Antonio. The shore line near Pernambuco is wooded, but a certain distance around the city the forests are cut down to give way to fields and sugar-cane plantations.

Thus, owing to the vast primeval forests on the Upper Amazon and its tributaries, the temperature of the hottest month and the extreme maximum are not greater than on the seacoast, and the extreme maximum is far from reaching the values sometimes observed in middle latitudes. It is also to be observed that there are few regions on the earth where the "Trades" blow with such violence as on the coasts of northern Brazil. Pernambuco is therefore subject not only to the influence of the sea but also to that of a furious trade wind. Along the lower course of the Amazon the "Trade" also blows with great force; but as soon as we turn into the side valley of one of the tributaries running in a southerly and northerly direction calm weather is found to prevail. The height and density of the forest arrests the wind. There can be no doubt that the vast tracts of forest land on the Amazon, contributing to maintain the moisture of the air and weaken its motion, increase the amount of waterfall. At Iquitos 284 centimeters fall in the course of the year. It must be remembered that Iquitos lies in a plain 2,100 kilometers from the ocean and 350 from the mountains. Nowhere on the earth is the rainfall so great under similar circumstances.

SUPPOSED INFLUENCE OF FORESTS UPON HAILSTORMS.

In this connection the claimed influence of forest areas upon hailstorms may be discussed. While in France the conclusion was reached that such influence existed, it is doubted by A. Bühler (Influence of topography and forests on frequency of hailstorms, 1890), who discusses this question on the strength of observations over the whole Kingdom of Wurtemberg through sixty years (1828–'87) in great detail. An influence either upon the frequency, intensity, or course of hailstorms, it seems, could not be established.

There is, however, in these statistics and the conclusions to be derived therefrom one factor, that must not be overlooked, and which the

able author does not fail to observe. It is the fact that these observations refer to a mountainous region throughout. That means that the influence which the forest areas might exercise in the distribution of hailstorms is vitiated or wiped out by the more potent influence of slope and elevation. It is, therefore, impossible to study the isolated forest influence in such regions where other known but quantitatively undetermined disturbing influences must be discounted. For such studies the plain offers a more satisfactory field. The forest on hilly or mountainous terrain is never effective by itself; it could, therefore, here only be the question whether it plays a determinative or only a subordinate part. The forest besides is not like hill and mountain, a constant and evenly effective factor, since its condition and in most cases its area is constantly changing. The author also recognizes the fact that his material does not permit the discussion of the practically important question, whether and why, as is often observed, hailclouds will pass by single fields or confined areas within the general route of the storm. The careful observations of the route and extent of a hailstorm on June 6, 1891, in Thurgau, Switzerland, recorded in Meteorologische Zeitschrift, 1891, p. 403, would also show that at least in this case, in mountainous regions and with extraordinarily violent hailstorms, no effect of forest distribution was noticeable. The writer would recall here a case of his own observation on the North German plain, where the farm of one of his relatives of 5,000 acres is on three sides surrounded by forest areas of considerable extent. The owner for a long series of years has had no damage from hail, while his neighbor, only one mile outside of this forest-inclosed district, reaps the benefit of his hail-insurance money every other year.

INFLUENCE OF FORESTS UPON THE DISPOSITION OF THE WATER SUPPLY.

(1) ELEMENTS OF DISSIPATION.

In analyzing the relation of forests to the conservation of the water supplies, we shall examine first the factors of dissipation, or those which diminish the available supply. They are represented in the quantity of water which is prevented by interception from reaching the ground, in the quantity dissipated by evaporation, in the quantity used by plants in their growth, and in transpiration during the process of growing.

Interception.

The amount of rainfall and snow which is prevented by a forest growth from reaching the soil varies considerably according to the nature of the precipitation and the kind of trees which form the forest as well as the density and age of the growth.

A light drizzling rain of short duration may be almost entirely inter-

cepted by the foliage and at once returned to the atmosphere by evaporation; if, however, the rain continues, although fine, the water will run off at last from the foliage and along the trunks. And this amount, of which the rain-gauge takes no account, represents, according to measurements from the Austrian stations, from 8 to 14 per cent, thus reducing considerably the loss to the soil by interception.

While the careful measurements at the Swiss stations in a twelve years' average show the interception in a larch forest as 15 per cent, in a spruce forest 23 per cent, in a beech growth 10 per cent, the figures for the Prussian stations are for beech growth 24 per cent, for spruce at various stations 22 per cent, 27 per cent, and 34 per cent, respectively. Altogether, for the rainfall conditions of the countries cited, a dense forest growth will, on the average, intercept 23 per cent of the precipitation; but if allowance be made for the water running down the trunks, this loss is reduced to not more than 12 per cent.* (See page 100 of this bulletin.)

According to A. Matthieu's observations during eleven years at Cinq-Franchées (Météorologie comparée agricole et forestière, 1878), only 8.5 per cent were retained by crowns (5.84 per cent in winter, 11 per cent in summer). The more exact observations of Riegler are compiled as follows:

Species.	Rain on crown.	Fell through the crown upon soil.	Run off trunk.	Reached soil altogether.	Lost by evaporation.	Percentage of rain reaching soil altogether,
	Liter.	*Liter.*	*Liter.*	*Liter.*	*Per cent.*	
Beech	26,021	17,068	3,343	20,411	21.8	78.2
Oak	24,273	17,873	1,387	19,260	20.7	79.3
Maple	36,901	26,384	2,198	28,582	22.5	77.5
Spruce	12,044	4,793	165	4,958	58.8	41.2

The results for spruce become vitiated by the fact that large amounts of water run off from the tips of the branches, which have an inclination away from the trunk, and which could not be measured.

The intensity of the precipitation and the condition of foliage have much to do with the amounts reaching the soil, so that sometimes practically all the rain reaches it and sometimes hardly any.

The amount of interception in the open growths which characterize

* The maximum rainfall observed in Germany is 4 inches in twenty-four hours and 2 inches in one hour. In Switzerland there has been recorded a rainfall of 18 inches in twenty-four hours, and 2½ inches in three-quarters of an hour. This would equal 5,000 gallons per acre. Of such falls the foliage will retain only an inappreciable amount. Intensity of rainfall in the United States becomes clear from a few records: Paterson, N. J., 1¼ inches in eight minutes; Sandy Spring, Md., 5 inches in two and one-half hours; Clear Creek, Nebr., 4.50 inches in one hour and twenty-seven minutes; Castroville, Tex., 5.80 inches in twenty-four hours; Ellsworth, N. C., 13 inches, of which 9 inches in three and one-half hours; and rainfalls from 1½ to 4 inches per twenty-four hours are quite frequently reported in almost every month, especially in the Western States.

many of our western forest areas would be considerably smaller, especially as the rains usually fall with great force, and much of the precipitation is in the form of snow. Although branches and foliage catch a goodly amount of this the winds usually shake it down, and consequently but very little snow is lost to the ground by interception of the foliage.

There is also a certain amount of water intercepted by the soil cover and held back by the soil itself, which must be saturated before any of it can run off or drain away. This amount, a part of which is eventually dissipated by evaporation and transpiration, depends, of course, upon the nature of the soil and its cover, especially upon their capacity to absorb and retain water.

Altogether an appreciable amount of the precipitation does not run off or drain through the forest cover but is retained by it; yet while this is apparently a loss, we shall see further on that this moisture retained in the upper strata fulfills an important office in checking a much greater loss due to evaporation, and thus becomes an element of conservation.

Evaporation.

The loss by evaporation, after the water has reached the ground, depends in the first place upon the amount of direct insolation of the soil, and hence its temperature, which again influences the temperature of the air. The nature of the soil cover, the absolute amount of moisture in the atmosphere, and the circulation of the air are also factors determining the rate of evaporation.

A considerable amount of experimental data is available showing the rate and total quantity of evaporation in different climates and at different seasons. Recent observations made by the U. S. Signal Service and the Geological Survey show that the evaporation from a water surface on the western plains and plateaus of the United States may amount to from 50 to 80 inches, and in special localities to even 100 inches, in a year, while the rainfall (diminishing in reverse ratio) over this area is from 30 to 12 inches and less. Thus in Denver, where the maximum annual precipitation may reach 20 inches, the estimated evaporation from a water surface during one year was 69 inches.

These experiments, made by the Signal Service and the Geological Survey, have thus far referred only to the rate of evaporation from water surfaces; the much more difficult question of the rate of evaporation from soil surfaces has been the subject of tentative experiment, but as yet without such results as can here be generalized.

If the loss by evaporation from an open field be compared with that of a forest-covered ground, it will, as a matter of course, be found to be less in the latter case, for the shade not only reduces the influence of the sun upon the soil, but also keeps the air under its cover relatively moister, therefore less capable of absorbing moisture from the soil by evaporation. In addition, the circulation of the air is impeded be-

tween the trunks, and this influence upon available water supply, *the wind-breaking power of the forest*, must be considered as among the most important factors of water preservation. Especially is this the case on the Western plains and on those Western mountain ranges bearing only a scattered tree growth and where, therefore, the influence of shade is but nominal.

The evaporation under the influence of the wind is dependent not only on its dryness, but also on its velocity, which being impeded, the rate of evaporation is reduced.

Interesting experiments for the purpose of ascertaining the changes in the rate of evaporation effected by the velocity of the wind were made by the Signal Service in 1887. The result of these experiments (made with Piche's hygrometers whirled around on an arm 28 feet in length, the results of which were compared with those from a tin dish containing 40 cubic centimeters of water exposed under shelter) show that with the temperature of the air at 84 degrees and a relative humidity of 50 per cent., evaporation at 5 miles an hour was 2.2 times greater than in a calm; at 10 miles, 3.8; at 15 miles, 4.9; at 20 miles, 5.7; at 25 miles, 6.1, and at 30 miles the wind would evaporate 6.3 times as much water as a calm atmosphere of the same temperature and humidity.

Now, if it is considered that the average velocity of the winds which constantly sweep the Western subarid and arid plains is from 10 to 15 miles, not rarely attaining a maximum of 50 and more miles, the cause of the aridity is not far to seek and the function of the timber-belt or even simple wind-break can be readily appreciated.

What the possibilities of evaporation from hot and dry winds may be, can be learned from statements regarding the "Foehn," which is the hot wind of Switzerland, corresponding to the "chinook" of our Western country.

The change in temperature from the normal, experienced under the influence of the Foehn, has been noted as from 28° to 31° F. and a reduction of relative humidity of 58 per cent. A Foehn of twelve hours' duration has been known to "eat up" entirely a snow cover of 2½ feet deep.

In Denver a chinook has been known to induce a rise in temperature of 57° F. in twenty-four hours (of which 36° in five minutes) while the relative humidity sank from 100 to 21 per cent.

The degree of forest influence upon rate of evaporation by breaking the force of winds is dependent upon the extent and density of the forest, and especially on the height of the trees. For according to an elementary law of mechanics the influence which breaks the force of the wind is felt at a considerable elevation above the trees. This can be practically demonstrated by passing along a timber plantation on the wind-swept plains. Even a thin stand of young trees not higher than 5 feet will absolutely calm the air to a considerable dis-

tance and height beyond the shelter. Unfortunately no accurate experimental data concerning this influence are at hand. According to Becquerel, a simple hedge 6 feet in height will give protection for a distance of 70 feet; and, according to Hardy, a belt of trees every 300 feet will defend vegetation almost entirely against the action of the wind. Another authority finds for every foot in height 1 rod in distance protected. (See also p. 149 of this bulletin.)

From many reports received in this office on the effects of windbreaks upon agricultural crops, we may quote one from a farmer in Illinois, which expresses the observations generally made:

> My experience is that now in cold and stormy winters wheat protected by timber belts yields full crops, while fields not protected yield only one-third of a crop. Twenty-five or thirty years ago we never had any wheat killed by winter frost, and every year a full crop of peaches, which is now very rare. At that time we had plenty of timber around our fields and orchards, now cleared away.

The damage done to crops by the cold, dry winter winds is mainly due to rapid evaporation, and plants are liable to suffer as much by winter as by summer drought.

This is certain, that since summer and winter drought, *i. e.*, rapid evaporation, due to the continuous dry winds, is the bane of the farmer on the plains, rationally disposed timber belts alone will do much to increase available water supply by reducing evaporation.

How the forest cover, and especially the litter of a well-kept forest, may decrease the amount of evaporation within the forest to nearly seven-eighths of that in the open has been discussed on page 99 of this bulletin. The reason for this important influence of the forest is due not only to the impeded air circulation, but also to the temperature and moisture conditions of the forest air and forest soil.

The stations of Prussia allow the following average for evaporation; the amount evaporated in the open fallow field being called 100:

	Evaporated.	Retained more than in open fallow field.
	Per cent.	*Per cent.*
Under beech growth	40.4	59.6
Under spruce growth	45.3	54.7
Under pine growth	41.8	58.2
From cultivated field	90.3	9.7

A balance calculation of the amounts of precipitation and the amounts lost by evaporation for sixteen stations at varying elevations shows that with increasing altitude the surplus of water remaining for the soil increases, the mountain forest decreasing evaporation to its minimum of 9 to 13 per cent, and leaving from 87 to 91 per cent to penetrate the soil.*

* This is a larger amount than that given on page 101, where the water running off the trunks of trees is counted as lost.

Stations.	Altitude.	Surplus of precipitation over evaporation.		Of percipitation evaporated.	
		In the open.	In the forest.	In the open.	In the forest.
	M.	*Mm.*	*Mm.*	*Per ct.*	*Per ct.*
Schoo	3	322.5	343.6	55	28
Fritzen	30	387.5	322.5	40	28
Hadersleben	34	495.8	481.4	35	20
Eberswalde	42	142.1	237.5	73	44
Lintzel	95	174.6	180.6	70	67
Average for the region	0-100	305.3	313.1	55	37
Kurwien	124	346.1	365.7	44	26
Marienthal	143	184.9	254.7	68	37
Hagenau	145	436.1	434.3	46	26
Average for the region	100-200	322.4	351.6	53	30
Neumath	340	328.5	510.9	60	23
Friedrichsrode	353	291.0	385.8	57	26
Average for the region	300-400	309.9	448.3	58	25
Lahnhof	602	850	685.2	24	15
Hollerath	612	717.5	490.2	26	21
Schmiedefeld	680	1,468.2	1,114.3	13	7
Carlsberg	690	718.8	839.1	27	10
Average for the region	600-700	938.7	782.2	22	13
Sonnenberg	774	1,196.4	1,093.8	15	9
Melkerei	930	1,142.1	1,196.8	19	11

Altogether, it will have to be admitted that the factor of dissipation represented in the evaporation from the ground is considerably reduced by the forest-cover; and since the rate of evaporation in our Western Territories is probably the greatest element in the dissipation of moisture, the greatest attention to checking it will be necessary in the husbanding of water supplies. This check to evaporation refers not only to the preservation of the water supply where it falls, but also in the natural and artificial channels through which it may be conducted or in the reservoirs where it may be stored.

The surface exposed determines the amount of evaporation from water-courses and reservoirs; but if the amount evaporated is related to the available volume of water, it will appear that the smaller and slower run loses proportionately more than the larger, which thus exhibits the value and protective character of accumulation.

Take a brook 6 feet in width and only a foot in depth; this for a length of 30 feet would contain 180 cubic feet of water. If from this surface only one-tenth of 1 inch evaporates, the amount evaporated is equal to 1.5 cubic feet or $\frac{1}{120}$ of the entire supply. On the other hand one-tenth of 1 inch evaporation from a river 60 feet broad and 12 feet deep for a length of 30 feet, containing therefore 21,600 cubic feet of water, would bring the loss to 15 cubic feet or only $\frac{1}{1440}$ of the available supplies; the loss, in proportion to the supply, being twelve times greater in the former case.

Transpiration.

All vegetation takes up a certain amount of water, a part of which is consumed in building up its body, and a still larger part returned to the atmosphere by transpiration during the process of growth.

The factor of dissipation having been fully discussed on pp. 96, 130 of this bulletin, it need not be further considered here, except to recall the conclusion that forest growth transpires considerably less than other kinds of vegetation.

Since this water is given off again to the atmosphere in the locality where it has fallen—thus enriching the atmospheric moisture—and is therefore only diverted temporarily for the purpose of doing duty in producing useful substance and retaining it in the locality where it has fallen for a longer time, transpiration may even be considered as an element of conservation.

There is still to be considered a certain amount of moisture which is retained and stored up in the body of the plant, partly as a necessary permanent constituent, partly as a temporary constituent, being evaporated when the plant dies or the wood is seasoned. The amounts thus retained vary considerably according to age, capacity for transpiration, site, soil, climate, density, slow or rapid growth, weather, seasons, and even the time of the day. It is therefore almost impossible to give anything but very rough approximations, especially as also the different parts of the tree vary considerably in the amounts of water present.

The water which enters into chemical composition of the wood substance represents about 50 per cent of the weight of dry substance.

The water hygroscopically retained in the living tree varies within the wide range of from 18.6 to 51.8 per cent in the wood, while the leaves contain as much as 54 to 65, and some even over 70 per cent while living; when dry, still 10 to 12 per cent. The wood of deciduous hard woods, like oak, ash, elm, birch, beech, contain in the average 38 to 45 per cent; soft deciduous trees 45 to 55 per cent, and the conifers 52 to 65 per cent. White pine when young may show as high as 77 per cent of its weight as water, while larch, of all conifers, has the smallest water capacity, namely, 45 to 55 per cent, ranking with the deciduous soft woods.

This hygroscopic water is reduced by seasoning to 10 or 12 per cent; this amount being retained even in well seasoned woods.

Given the entire mass of wood and foliage on an acre of forest, an approximative calculation of the total quantity of water contained in the trees will show that 56 to 60 per cent of the weight of the forest must be attributed to water, while only 44 to 40 per cent is represented by dry substance. In agricultural crops it is known that the amounts of water are still larger, reaching sometimes 95 per cent of the whole weight. The production of dry substance in a well-kept dense timber forest may amount annually to from 2,500 to 3,000 pounds per acre, leaving, then, for the hygroscopic water, 3,750 pounds, and the chemically fixed water, say, 1,250 pounds; so that for this factor of dissipation 5,000 pounds in round numbers as a maximum will suffice.

ELEMENTS OF CONSERVATION.

In discussing the elements of dissipation as to the degree of their effect under forest-cover, compared with the same elements at work in the open field, we have seen that the shade, the low temperature, the relative humidity, the absence of violent air-currents, the water capacity of the forest floor, are all acting as factors of conservation. We have seen that the quantity of water lost by evaporation—the most fruitful source of dissipation—may be more than six times as great in the open as in the forest. There is only one other element of conservation affecting water supplies which requires special mention. This is the retardation in the melting of the snow, which is due to forest-cover. According to Dr. Bühler, of Zurich, this retardation in Switzerland amounts to from five to eight days in general, and may, according to weather conditions, be several weeks, thus giving a longer period for distribution. The evergreen coniferous forest in this respect naturally does better service than the deciduous one.

Effect of forests in case of snow.

Snow will lie in the forest more evenly and continuously than on the open, wind-swept areas. Thereby not only the amount finally remaining for drainage is increased, but the soil is prevented from freezing, and is kept open for percolation when the snows melt. The retardation of the melting has been determind by Bühler in Switzerland to be from eight to fourteen days.

Mr. R. U. Piper, in his Trees of America, states that an unobstructed warm wind will dissolve the snow more than ten times as fast as when it is protected from the wind, the temperature being the same, and he adduces in verification of his statement the following experiments tried by himself: In the first, a body of snow 1 foot in depth, protected from the wind, but partially exposed to the sun, after a thaw of two weeks, was not wholly melted, while another mass 6 feet in depth, more sheltered from the sun, but fully exposed to the wind, was melted in less than a week.

In the second, equal quantities of snow were placed in vessels of the same kind and size and exposed to the same temperature, one being covered and the other having a current of air constantly passing over it. The snow in the latter vessel was melted in sixteen minutes; that in the former was not entirely dissolved at the end of eighty-five minutes.

In the third experiment, in a room with the temperature above 80°, the mercury in a thermometer rose from 32° to 80° when exposed to a warm current created by a fan, or seven times as fast as when the heated air was still.

The conservative effect of the forest-cover is especially of value on the western mountain ranges, which are liable to be swept by the

chinook, dissipating as if by magic the snow-cover over which it sweeps. (See p. 133.)

Even without this specially dry wind it is well known in Colorado and other mountain districts that the regular wind sweeping over the bare slopes above timber line, or where the forest-cover is removed, while they drift the snow hither and thither, they "wear it out" at the same time. By the blowing of the wind the snow is reduced to finest particles, and, by the shifting, new surfaces are constantly exposed—two processes which greatly facilitate evaporation, and thus the snow is literally worn out.

The proposition, then, to remove the forest-cover in order to allow the drifting and compacting of the snow, from which possibly to secure a longer period of distribution, even if there were no other objection, must be considered a hazardous and ill-advised expedient.

The influence of the forest upon the condition and drifting of the snow is graphically related by Middendorff in his description of Siberia, speaking of the Buran or snowstorm characteristic of the treeless plains of tundras:

As far as the forest reaches and impedes the action of the winds the snow lies everywhere evenly and loosely, so that in the beginning of winter one can travel only on snowshoes. As soon as the tundra is reached there is no need of snowshoes. The snow lies either like a thin carpet, or drifted together in incredible masses, so compacted as to bear man and beast, etc.

General effect of forests in reducing evaporation.

The popular notion which ascribes to the moss-cover or spongy character of the forest floor a conservative function beyond that of retarding evaporation and expediting infiltration seems to be entirely erroneous and needs revision. The idea that the moisture of the soil and the flow of springs is increased by water from the spongy cover is altogether in contradiction to physical laws, and can be shown experimentally to be a mistaken one.

Water filters through the cover by the law of gravitation until the whole mass has become fully saturated. With an addition of water it will filter through to the soil, as long as the supply continues and as long as the soil is not so saturated that it can not readily absorb any more water. At last, the supply continuing, the cover will refuse to convey it and will shed it superficially, leaving opportunity to reach the soil only where the moss-cover is interrupted. When the water supply ceases, evaporation begins above, and by capillary attraction the cover supplies its loss of water on the surface from the soil below.

To give water to the strata below, it would be necessary that these should have become dry, or at least drier than the moss-cover before the latter had lost its water. This may occur and depends naturally upon the structure and nature of the soil. If the soil is strongly fissured, thus rapidly draining the upper strata, then, if the moss-cover is still

saturated and an additional pressure is exerted by water standing or falling on it, a further supply of water may be given up to the soil; if, however, the moss is only just saturated and no further access of water takes place from above, then there is no physical law by which a surrender of this saturation water to the soil could take place as long as the underlying soil is of a gravelly or nonabsorbing nature. If its nature is like clay, marl, fine sand, capable of attracting water, then the further process of water absorption depends upon the difference between the water capacity of the cover and that of the soil.

In a sand soil in which the upper strata lose their water rapidly to the lower, the moss-cover, which holds water more tenaciously, can be made to give up water to the soil as long as the capacity for absorption by the sand is greater than the capacity for retention by the moss.

A loam or clay soil takes up water very slowly, but takes up a great deal before it is saturated, and the process of filtration goes on very slowly; if, therefore, a plentiful rain falls, there is formed under the moss-cover a shallow, nearly saturated layer of soil, which acts as an impermeable stratum. This layer is protected by the cover against rapid surface drying, and since it gives up its water only slowly to the lower strata, it remains moist so long as the moss-cover is not dry. As soon as by evaporation the cover has lost its water, the soil must give up some of its moisture by capillary attraction to supply the deficiency in the cover. It must be noted here, however, that according to Oltman's experiments, moss does not take up water from an only moderately moist soil. A deficiency of moisture occuring in soil earlier than in the cover can be presumed only when the water is utilized by the roots and transpired, which is not likely to occur.

These are the extreme cases between which in nature many intermediary conditions occur. The litter cover does not act analogously to the moss-cover or to a sponge. A difference must here be noted between the newly fallen loose litter of the previous year and the closely packed and felted litter accumulations of former years. The former allows a rapid filtration; the latter, according to Riegler's experiments, is nearly impermeable, and the water practically can enter the soil only where the litter is interrupted. The compacted litter serves admirably to retard evaporation. In reality there rarely exists an uninterrupted cover of such litter or a cover of one uniform nature; open spaces, moss-covers, varying thicknesses of litter-cover interchange, and accordingly the water penetrates readily, while the cover performs its duty as a conserving agent against evaporation.

There is an additional conservative action of the forest floor to be noted, which will be more fully discussed further on, as an influence upon the distribution of the run-off. It is the mechanical protection which the cover affords against the compacting of the soil by the falling raindrops; by this protection the soil is kept porous, permits ready percolation, and therefore less water remains at the surface to fall a prey to evaporation.

It is, then, *the protection against evaporation alone*, due to greater relative humidity of the forest air, to the shade, to the breaking of the winds, and especially to the protective soil cover, which *makes the forest a conservator of moisture everywhere*, even where it does not by its peculiar location increase the amount of precipitation.

Springs, then, may be influenced in the amount of their discharge by a removal of the forest, not because the forest supplies them directly with more water, but because by its removal the rate of evaporation is increased.

SUMMATION OF THE CONSERVATIVE AND DISSIPATIVE INFLUENCES.

The total conservative action of the forest with reference to available water supplies, aside from an increase of precipitation, is expressed by the difference between the elements of dissipation and those of conservation; the former comprised in the loss of the water by retention or interception, evaporation, and transpiration, the latter in the protection against evaporation. This balance is known to be in favor of the forest cover in some localities and under certain given conditions; but it will have become apparent that a general statement or quantitative expression of the amount of benefit is in general quite impossible. Yet in an ingenious manner a calculation for one of the Prussian mountain districts is proposed by Dr. Weber as follows: Using the figures which are exhibited in the table on page 113 he argues that the amount of water left, over and above the amount evaporated in the open at low altitudes, deducted from the amount left over and above evaporation in the forests of high altitudes, will suffice to cover the amount of transpiration; thus, in the spruce forest at the station of Sonnenberg, the surplus of precipitation above the water needed for evaporation had been 1,093.8 mm.; deducting from this the quantity which was found remaining in the open at Schoo, and which would suffice for purposes of transpiration and plant growth, a balance for drainage of 771.3 mm. results; for the beech forests at Melkerei and Hadersleben, the calculation gave a balance of 1,176.8−495.8=681 mm. for drainage. On the average, therefore, 700 mm. of the precipitation in the mountain forest in this locality are saved for the "run-off," that is, 100,000 cubic feet of water per acre.

To get a conception of what these 100,000 cubic feet mean in the river flow, it may be stated that with average water level the Rhine above Manheim has a flow of 47,700 cubic feet per second, an amount which would be yielded by 40,000 acres of mountain forest, provided all water is drained into the river; and to keep the river continually flowing at this rate would require, on the basis of these figures obtained experimentally, a forest area of 23,472 square miles, a calculation which by no means leads to absurd results for practical probability, since the drainage area of that part of the river is in reality about 30,000 square miles, largely in forest.

I also recall here the water balance drawn for the upper Elbe River watershed on p. 128, from which it appears that the river flow represents about 25 per cent of the precipitation.

The amount of river flow, to be sure, does not permit a calculation of the amounts of water originally available (after they have fallen and been diminished by the factors of dissipation) for local use in both subterranean and surface runs, since the river flow exhibits both kinds of drainage, but not at the same time. Nor do the wholesale methods sometimes employed to determine the relation of river flow to precipitation promise a solution of either that question itself nor of the question, how far surface conditions of the soil have a bearing upon drainage.

A detailed study of smaller and confined catchment basins alone like those referred to hereafter (see p. 154) will give results that may eventually lead to practicable methods of calculations.

DISTRIBUTION OF TERRESTRIAL WATERS.

The distribution of the available water supply is almost as important and often a more important factor in the economy of the water than the quantity of available supply itself, and the manner in which this distribution takes place influences considerably the ultimate availability of the supply for human use.

In discussing the distribution of the water supply it is desirable to follow the natural division of the waters into superficial and underground drainage. The surface run-off gives to brooks and rivers all their rapid variations of stage; the underground drainage gives them their permanent régime.

ANALYSIS OF DETERMINING INFLUENCES.

The proportionate division of these two classes of run-off, then, is of the highest possible importance; we will, therefore, analyze the conditions which determine their relative proportion in order to find how the forest may influence the same. It is evident that the first condition is to be found in the amount and character of the precipitation. A violent rainstorm will furnish more superficial run-off than when, the rain falling slowly, time is given for the soil to absorb it.

Rainy and rain-poor or arid climates, short and insignificant rains, short but violent, long and mild, or long, plentiful rains, also periodical, seasonal rains and irregular rainfalls, all these constitute differences in the nature and time of occurrence of the rainfall, which must necessarily affect the relative amounts of the run-off. The effect is still further complicated where the precipitation is partly snow, when not only the mass of accumulated supply but also the progress of melting determine the result of the run-off.

We find, therefore, based upon this one factor, namely, the nature and time of occurrence of precipitation, differences in the run-off which

are dependent upon differences in climatic conditions. Thus tropical rivers show one or two regular high stages of water according to whether they have one or two rainy seasons; in regions of equinoctial rains a spring and fall freshet is normal, while the rivers may be almost dry in summer or winter; the frequent thunderstorms in the mountains of Switzerland produce short but rapid floods during the summer, while the autumn is characterized by low water in the rivers. This climatic difference in water flow it is important not to forget when discussing the influences which may modify the discharge of waters.

W. Ule, in Meteor. Zeitschr., 1890, discusses the relation of water stages in a stream and outflow in relation to precipitation. He comes to the result that a direct relation from one to the other is impossible to find, because of the complication of other conditions, which disturb this *a priori* seemingly direct relation.

He finds that amount of precipitation and water stages or even water stages and amount of water flow are not proportional, so that with the same water stage different amounts may run off. If this discrepancy appears in the annual mean water flow, it is still more noticeable in the monthly means. In the river Saale the mean water stage for March, 1886, indicated a flow of 378,000,000 cu. m., while the daily measurements gave 508,000,000, or 34 per cent more. The mean water stage in March was 2.13 m., in December 2.15 m. Yet the amount of flow in the latter month was 23 per cent smaller than in the former. With the stage twice as high it was found that three times the flow resulted. From these more detailed measurements it appears that changes in the amount of river flow are not necessarily due to changes in amount of precipitation.

In 1886 the amount of river flow was 14 per cent less than in 1884, although the precipitation was by 1 per cent less in 1884.

The greatest influence on river flow is assigned to the distribution through the year of the precipitation, at least in regions with persistent frost periods, where, as in the Saale catchment basin, the river flow in winter is three times as great as in summer, namely, 51 per cent of the precipitation in winter against 17.3 per cent in summer. Hence the annual mean river flow reflects more the winter precipitation than those of summer, as the following figures show:

	Year.		Winter.		Summer.	
	1882–'83.	1884–'85.	1882–'83.	1884–'85.	1882–'83.	1884–'85.
Precipitation	10,913	10,757	4,441	4,047	6,572	6,710
River flow, cubic meters, millions	4,476	3,182	3,340	2,142	1,127	840

The larger amount of flow in 1882–'83 seems to depend on the fact that much precipitation fell in winter, and, at the same time, the greater percentage of flow in that winter is accounted for from the daily meas

urements showing repeated high rises, which, as has been shown, predicate disproportionate flow. The winter besides was warm, most of the precipitation was rain, or, if snow, was quickly melted and carried off. We see then that, besides the local and timely distribution of precipitation, temperature, direction and strength of winds, condition of topography and soil, other dynamic influences are exhibited in the river flow, which make this as an immediate expression of condition of precipitation uncertain.

After water has reached the ground its distribution is determined, first, by the character of the topography and, second, by the nature of the soil and the surface conditions.

The topography determines the rapidity of run-off and of collection. The more diversified the country—cut into dells, coves, rills, and furrows, steeper and less steep slopes—the larger the number of runs of unequal length in which the water is collected, while the less diversified the contour the more water must be carried off in each run. Yet where the diversity of configuration is accompanied by steep slopes the run-off may be so rapid that the valley river is filled more rapidly than the river of the open plains country with even slopes of moderate inclination.

Thus in some of the river valleys of West Virginia the watersheds are scooped out into such an array of coves, gashes, and water courses and minor watersheds, and so steep and rapid in descent that, in spite of the forest cover, a rainfall of a few days will induce a rapid rise of the rivers, while the same amount of rain will hardly wet the ground in a prairie country like Iowa.

The second of the above-mentioned conditions determining distribution—the nature of the soil and the surface conditions—comprises a large number of separate, though related, factors. The composition, structure, and stratification of the soil itself, its water capacity, its permeability, and other physical properties; the nature of the underlying rock and its susceptibility to disintegration under the action of erosion; the surface conditions of the soil cover, whether frozen or sunbaked, cultivated or uncultivated, barren or covered with grasses or forests; these are a part of the factors which affect the distribution of the water supply and determine the proportions of surface and underground drainage.

On a given territory, then, with given geologic, topographic, and climatic conditions, the only directly variable conditions influencing the manner of drainage are those of the upper soil strata of the soil cover. We are, then, mainly concerned with the water capacity of soils and soil covers, the intensity of their water absorption and the amounts of water which are drained through them in given times. We are interested in studying by what means the draining capacity of the soil is increased, and by what means altogether the run-off may be changed in its nature from a superficial to a subterranean one and the reverse.

WATER CAPACITY AND WATER CONDUCTIVITY OF SOILS AND SOIL-COVERS.

We must discern two kinds of water capacity in soils, namely, the absolute or minimum water capacity and the full or maximum water capacity. The former, also called "moisture coefficient" in soil analyses, is that water quantity which the soil will retain, no matter what the drainage conditions, provided the supply is not deficient. It is this water retained in the capillaries which determines the designation of the soil as moist, wet, or dry, which latter is only comparatively so. If the drainage is impeded by an impermeable layer underlying a porous, permeable surface soil, and if the slope of the impermeable layer does not favor rapid drainage, then if additional supplies reach the soil, all interstices and largest capillaries will fill up and the amounts of water then contained in the soil represent its greatest (full or maximum) water capacity. Any surplus above this greatest water capacity is bound to drain off at once either superficially or subterraneously.

Absolute or minimum water capacity of soils according to Von Klenze.

[Volume unit, 3.5 cm. diam. by 10 cm. height.]

Soil.	Height of layer in centimeters.	Weight of water absorbed in grams.	Volume.	Relation of weight to volume.
			Per cent.	
Sand, loose	10	44.6	26.99	44.6
	20	68.0	24.04	34.0
	30	83.8	20.37	27.2
	40	92.9	17.58	23.2
Loam, fine, loose	10	43.5	48.27	43.5
	20	76.2	47.59	38.1
	30	106.8	42.68	35.6
	40	138.2	38.42	34.5
Humose lime sand, loose, fine	10	48.2	49.13	48.2
	20	79.2	47.87	39.6
	30	113.1	45.11	37.7
	40	129.2	43.60	32.3

Full or maximum water capacity of soils according to Meister.

[Volume unit 1 cubic foot].

Soils.	Weight of water absorbed.	Volume.
	Pounds.	*Per cent.*
Clay	21.99	50.0
Loam	26.40	60.1
Humus	30.90	70.3
Peat	27.99	63.7
Garden mold	30.33	69.0
Lime	24.09	54.9
Chalk	21.74	49.5
Sand (82 per cent)	19.94	45.4
Sand (64 per cent)	28.67	65.2
Quartz sand	20.42	46.4

From the above tables it appears that with the depth of the soil the minimum water capacity varies greatly, and the same may be expected for the maximum water capacity. In sand it may sink within 15 inches

to one-half of what it is at the surface, while in loam, owing to smaller capillaries, the reduction is only one-third. The finer the capillaries the more water they can keep up proportionately in balance against the force of gravity, and hence humus and garden mold, with their fine capillaries, show the greatest water capacity.

The degree of such retention, as has been shown by Prof. C. E. Hilgard and others, is also somewhat influenced by the temperature of the soil. The least retentive soil is a coarse quartz sand followed by finer sands, and it is increased by an addition of lime loam, or vegetable matter.

For a "second-class" Florida sand soil the "moisture coefficient" is stated by Hilgard as 1.64 per cent of its own weight, while it is 23 per cent and more in a peat soil; a pure clay rarely exceeds 12, while the moisture coefficient of calcareous clay soils rises to 15 and 20 per cent. The maximum water capacity may be many times that of the absolute water capacity, depending on structure and more or less compact stratification of the soil. According to Ebermayer, the amounts of water held may vary between 3 and 88 per cent. Dr. Raman's investigations show the maximum water capacity of sand soils of fine and medium fine texture to be from 3 to 4 per cent.

According to Prof. Schuebler at Tübingen, who experimented on soils under natural conditions:

Sand soil may hold 25 per cent of its weight in water; loamy soil 40 per cent of its weight in water; clay loam 30 per cent of its weight in water; pure clay soil 75 per cent of its weight in water.

The most impervious soils, as was to be expected, showed the greatest retentive power, and since by compacting the soil particles the capillarity is increased, the imperviousness of such soils is increased.

Impermeable soil strata, such as loam and very fine sand, allow, when a surface run-off is readily possible, only a passing and inferior retention of water after rainfall, in springtime taking up no more than 10 or 12 per cent of their weight, while a stratum of sand of medium grain, 20 to 25 feet deep, was calculated by Raman to be capable of taking up and holding the entire annual precipitation of 24 inches.

The capillarity of sand soils of the North German plain investigated by Raman was not capable of raising the ground water higher than 1½ feet, so that the upper strata of the soil, which was within reach of ground water, did not show any greater amount of water than the soil which had no ground water to fall back upon.

Mr. F. H. King (Agric. Expr. Sta. Wisc. Ann. Rept., 1889) has investigated the water capacity of soils with special reference to the function of ground water in plant production. Six thousand observations of ground water stages under varying surface conditions show insufficiency of capillary actions to supply water for plant transpiration rapidly enough. He found that a column of 1.5 in height of natural soil (consisting of loamy marl, red clay, sandy clay, and fine sand) could hold an amount

equal to 54 cm. precipitation, which is equal to three-fifths of the mean annual precipitation at the station, of which the author presumes not more than 30.5 cm. are used for an average crop of agricultural grains.

Coming now to the influence which a forest cover may have upon the water capacity of the soil, we have to record the results of Dr. E. Ebermayer, who has investigated the water capacity of a heavy loam soil, both protected and unprotected by a forest cover.

The following table contains the measured amounts of water contained in such a soil under a forest of spruce, twenty-five, sixty, and one hundred and twenty years old, and a naked soil at 16 inches (40 cm.) and 32 inches (80 cm.) depth.

Water contents of a loamy sand; results by seasons expressed in percentages of the weight of the soil.

Season.	Spruce.									Naked soil.		
	25 years old.			60 years old.			120 years old.					
	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.	16 inch.	32 inch.	Average.
Winter (January and February)	20.23	17.00	18.61	18.06	17.76	17.91	19.75	22.44	21.09	19.96	24.73	22.35
Spring (March to May)	18.62	18.02	18.32	15.29	16.28	15.78	17.47	20.83	19.15	20.66	20.51	20.58
Summer (June to August)	15.10	16.22	15.96	14.42	17.03	15.72	17.78	20.90	19.97	19.37	19.98	19.97
Fall (September to November)	16.57	17.57	17.07	13.49	16.52	15.00	14.88	19.46	17.17	20.04	20.20	20.12

These figures show that a loam soil under forest cover is apt to be drier in the depth of the root region, and that at all seasons, than in the open field at the same depth, less so under an old and scattered growth than under a younger growth or thicket.

A repetition of these experiments, in which various depths from the top to 32 inches were included, gave during two years the following averages of water capacity, expressed in percentages of the weight of the soil:

Averages of water capacity, expressed in percentages of the weight of the soil.

Depth.	Spruce.			Unshaded soil.
	25 years old.	60 years old.	120 years old.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0 to 2 inches	30.93	29.48	40.32	22.33
6 to 8 inches	19.19	18.99	19.30	20.62
12 to 14 inches	19.10	16.07	18.28	20.54
19 to 20 inches	18.40	16.26	20.16	20.14
30 to 32 inches	17.91	17.88	21.11	20.54
Average	18.65	17.30	19.71	20.46

Ebermayer combines the values for depths from 6 inches down to 32 inches, and then concludes that the forest soil is less moist, due to the transpiration of water by plants. This conclusion is, however, not at all warranted. For if one combines the figures found in all the strata from the top to 3 inches down, they figure as follows: Spruce 25 years

old, 24.79 per cent; spruce 60 years old, 23.39 per cent; spruce 120 years old, 30.01 per cent; naked soil, 22.39 per cent.

Hence, take it altogether, the naked soil contains considerably less water than the forest-covered soil. But the distribution of the water through the different layers of the soil is different in the two cases; the naked soil, due to rapid evaporation, no doubt, contains the least amounts in its upper strata, where the forest soil with its absorptive cover preserves the largest amount. Measurements of the stratum from 2 to 6 inches would probably have shown the preservative effect still more prominently.

The water capacity of soils and soil covers in general has been referred to as an element of interception. With reference to the run-off, this capacity becomes influential in determining the manner of run-off. As soon as the soil cover and the upper soil strata are saturated, and especially when the latter are more or less impermeable and the rain continues, either no water or only a small part gradually can find entrance into the soil, and the run-off becomes in the main superficial, or, if the ground be not sloping, stagnant water results.

For every watershed, no matter what its conditions, there may, therefore, come a time when the rain or snow-melting continuing, the entire run off becomes superficial, the soil being unable to take up more.

It is evident that this time must occur later in the forest than on the unforested and especially naked soil, because the water capacity of the soil cover as well as of the protected soil in the forest is greater than that of the naked soil or that covered with field crops.

The water capacity of litter, which Wollny investigated, depends on its nature and, of course, its thickness to a certain degree, and is quite considerable, much greater than that of soils.

The water capacity of various litters was found to be as follows in volume per cent:

Depth of litter.	Oak leaves.	Beech leaves.	Spruce litter.	Pine litter.	Moss.	Calcareous sand soil.
When 2 inches deep	50.77	....	38.93	....	19.82	....
When 12 inches deep	45.42	39.78	41.65	36.28	....	24.93

No soil cover was found so variable in water contents as moss, while litter would hold two or three times as much water as moss and twice as much as the soil.

The variation of water capacity at different depths appears from the following figures:

Depth of litter.	Oak leaves.	Spruce leaves.
Two inches	50.77	38.98
Four inches	52.99	47.76
Eight inches	53.09	41.03
Twelve inches	45.42	41.65

That is to say, the increase in water capacity ceases with about 8-inch depth.

The quantity of water which the soil cover can contain appears from the following measurements of Dr. Ebermayer: On the 17th of August, 1885, after rainy weather, the moss cover in a 60-year-old spruce growth contained 72.33 per cent at the top, 76.64 per cent on the lower side, and 71.67 per cent in the humus soil beneath.

After a rainstorm lasting one and a half days, on September 9, 1885, the moss cover contained 80.45 per cent at the top, 74.61 per cent on the lower side, and 74.42 per cent in the top soil.

In this connection the following note regarding the enormous water capacity of moss covers in Alaska may be of interest:

In the interior plateau of the Cordilleran and St. Elias regions of Alaska, according to Mr. C. W. Hayes, surface degradation is greatly retarded by the luxuriant growth of moss, which covers practically the entire surface of the country. The annual precipitation is largely confined to the winter months, and the water from the melting snow is held by the sponge-like moss, which remains saturated throughout the short but hot and dry summer. Thus, with a rainfall which, in lower latitudes, would condition an arid region, a large part of the surface is swampy, quite irrespective of slope—that is, wherever the material composing it is sufficiently compact to become impervious to water on freezing. On account of this slow and imperfect surface drainage, the slopes are not cut into the ravines and arroyas so characteristic of arid regions.

WATER CONDUCTIVITY OF SOILS.

Of still more importance for the run-off than the water capacity is the water conductivity of the soil, or the rate of water absorption—filtration.

The rapidity with which the water is conducted from above downward must necessarily influence the nature of the run-off.

Gravity tends to drain the water downward, capillarity to carry it upward; the difference of these two forces in the main must, besides the mechanical obstructions of the soil particles, determine the rapidity of drainage. Experiments to establish the rate under various conditions are very few and unsatisfactory.

The capillary conduction from below has frequently been made the subject of investigation, but the downward movement has not yet been studied with sufficient detail, and it has hardly yet been recognized by the experimenters that this depends upon the difference of gravity and capillarity as two opposed forces. According to E. Wollny's experiments in 1883 and 1884—

(1) Water is conducted downward the more rapidly the larger the soil particles (*i. e.*, the less capillary attraction exists).

(2) The noncapillary interstices of the soil accelerate the downward movement of the water (*i. e.*, the less mechanical obstruction of soil particles).

(3) In granular soil the water penetrates faster than in powdery soil (*i. e.*, penetration is the slower the denser the stratification). It is most rapid in quartz and slowest in clay; in humus at a rate between these two, but in a mixture of clay soil and humus faster than the average of the two.

(4) The rapidity of drainage in a granular soil is independent of the size of the grain.

The experiments were made with soils of varying grain in tubes 110 centimeters deep, the water dropping on top constantly; the results are exhibited in the following two tables:

Water conductivity in soil with varying size of grain.

Soils.	Water sank to a depth of—						
	After 5 minutes.	After 10 minutes.	After 15 minutes.	After 25 minutes.	After 45 minutes.	After 65 minutes.	After 120 minutes.
In soil of grain:	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
0.01 to 0.71 millimeters	8.8	12.8	16.2	21.3	30.0	36.7	52.0
0.071 to 0.114 millimeters	18.0	27.0	37.0	52.5	79.0	103.0	....
0.114 to 0.195 millimeters	28.3	48.0	65.0	96.0	....	....	....
0.175 to 0.2 millimeters	45.0	82.0	110.0	....	....	....	....
0.25 to 0.5 millimeters	84.0	....	....	....	....	....	....
Mixture of various grains	11.0	19.0	24.5	33.2	50.8	65.5	106.0

Water conductivity in granular soils.

Soils.	Water sank to a depth of—					
	After one-half hour.	After 1 hour.	After 3 hours.	After 4 hours.	After 23 hours.	After 59 hours.
Loam powder:	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
0 to 0.25 millimeters	9.0	32.1	20.2	23.4	57.4	97.6
0.5 to 1.0 millimeters	18.8	32.2	82.4	100.0	....	....
Loam granules:						
1 to 2 millimeters	19.0	32.2	83.1	100.0	....	....
2 to 4 millimeters	19.3	32.0	81.5	100.0	....	....
4 to 6.75 millimeters	18.8	30.4	77.5	99.6	....	....
6.75 to 9 millimeters	18.5	31.0	80.5	100.0	....	....
Mixture	4.0	8.0	11.0	19.5	24.1	100.0

According to Fesca the downward movement proceeds quickest in a dry dust, only slowly in clay soils; the same amount of water being drained through the former in one hour which it took two days to drain through the latter.

The influence of a soil cover on the physical condition of soils has been investigated directly by Wollny; he comes to the result that vegetation and cover with dead material (straw, litter, etc.) tend to preserve the loose granular structure of the soil.

The forest cover, then, has a tendency to preserve the granular, porous structure of the soil, which is favorable to filtration; and as, moreover, the roots furnish channels for unimpeded drainage, it must have the tendency, other things being equal, to allow a more rapid filtration than the naked, mostly compacted soil, or even that of a field of crops after cultivation ceases.

The temperature, too, appears to have an influence favorable to rapid filtration in the forest; for, according to Pfaff, in the field during winter three-quarters of the precipitation will sink to 2 feet depth in the soil, and not more than 10 to 30 per cent in summer.

Unless, therefore, the forest cover itself had a tendency to retard

penetration, which we will see is not the case, the influence of the forest upon the intensity of water absorption would be in the direction of diminishing superficial flow and facilitating subterranean drainage.

This factor is of the utmost importance in the discussion of the causes of floods. Without a consideration of the water capacity, and still more of the intensity of water absorption, it will never be possible to draw conclusions as to probable floods from the amount of precipitation alone.

The influence of various soil conditions and soil covers upon the amount of water that will filter through has been investigated by Wollny and Ebermayer in an extended series of experiments.

Experiments of this kind which will yield results applicable to natural conditions are exceedingly difficult to arrange, and require not only many precautions, but must be continued for a long time before generalizations can be attempted. One of Wollny's series of experiments was intended to show the influence upon filtration of a grass cover on different soils. The results calculated for 1 acre are as follows:

Kinds of soil.	Amount of filtration.	
	Fallow field.	Grass covered.
	Pounds.	*Pounds.*
Calcareous sand with humus	1,593,216	782,334
Quartz sand*	3,044,250	661,548
Loam soil*	1,529,671	59,105
Peat soil	2,048,124	405,162

* From May to November.

The grass cover, therefore, reduced considerably (by 50 per cent and more) the percolation of water. Ebermayer experimented with boxes 43 square feet surface (4 square meters) and 4 feet deep, filled with garden soil, leaving one bare, covering another with moss, and two others each planted with 6-year-old plants of beech and of spruce, with the following results, arranged according to seasons:

Year.	Rain.	Filtration water in height—			
		Under beech.	Under spruce.	Under moss.	Naked soil.
1886.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
March to May	156.98	12.65	10.52	16.96	10.93
June to August	560.22	15.89	12.09	31.60	26.13
September to November	114.45	1.12	0.76	7.17	3.27
December to February	126.30	9.73	5.98	11.40	9.08
Total	957.95	39.39	29.35	67.13	49.41
1887.					
March to May	219.20	10.61	5.05	14.40	9.97
June to August	210.60	2.50	1.49	13.00	3.91

In these experiments it is remarkable how small a percentage of the rainfall was filtered through, which would lead us to look at the results with caution, namely:

Of the total rainfall was filtered —

	1886.	1887.
	Per cent.	*Per cent.*
By soil covered with moss	7	6.2
By soil naked	5.1	3.5
By soil covered with beech growth	4.1	2.9
By soil covered with spruce growth	3	1.5

In regard to the amount of filtration which various soil-covers allow, we have the following very instructive results from the experiments of Wollny, in which the amounts of rain and corresponding filtration on 62 square inches suiface are given:

	May to September, 1886 — total rain 28,529 grams.		April to September, 1887—total rainfall 18,652 grams.	
	Amount, grams.	Per cent of rainfall.	Amount, grams.	Per cent of rainfall.
Oak leaves:				
5 centimeters	17,591	61.7	7,894	42.3
10 centimeters	19,482	68.3	7,353	39.4
20 centimeters	21,160	74.1	12,954	69.4
30 centimeters	21,061	73.8	13,272	71.2
Spruce litter:				
5 centimeters	17,793	62.4	8,653	46.4
10 centimeters	19,277	67.5	7,356	39.4
20 centimeters	19,523	68.3	14,611	78.3
30 centimeters	19,467	68.2	13,912	74.6
Pine needles:				
30 centimeters	19,734	69.2	9,784	52.4
Moss:				
5 centimeters	14,993	52.5	7,260	38.9
Bare soil:				
30 centimeters	11,610	40.7	3,636	19.5

These figures show that a litter will filter considerably larger amounts of water than a soaked soil of the same depth, and that the moss cover allows less water to filter than the litter. This is accounted for by the soil needing a larger amount of water to supply the moisture evaporated than the litter which remains moist.

Notable is the influence which the thickness of the cover exerts upon the amounts of drain water and also the relation of the amount of precipitation to the amount of filtration.

It will be noticed that with a thicker cover to 1 foot in depth (30 centimeters) the amount of precipitation hardly changes the amount of drain water, while the lighter covers have much less power to preserve a small precipitation, for of course the amounts not drained are evaporated.

E. Ebermayer (Sickerwassermengen in verschiedenen Bodenarten Wollny 1890) from a long series of experiments comes to the conclusion that besides clay, it is especially humus, which imbibes almost all precipitation and gives up very little water below.

A layer of garden mold of 1 m. furnished only 3.2, 5.7, and 7.1 per

cent filtration water from precipitation in fall, spring, and winter. "If, therefore, he says, our earth were covered with a humus soil of 1 m. in depth, subterranean drainage would be so slim that springs would be scanty and continuously flowing springs absent.

From these experiments it would then be conceivable that the forest floor could be of such nature as to prevent rapid filtration to the soil (close uninterrupted moss carpets, or compact humus), when with sudden large masses of rain falling less water would become available for underground drainage than without the forest cover. Such conditions, however, are exceptional; the possibility of their occurrence, on the other hand, makes it necessary in every additional case to ascertain not only the nature and stratification of the soil, but also the nature of the soil cover or forest floor, before we can determine whether or not the presence of the forest is conducive to practically greater percolation.

There is another element favorable to the absorption of water by the soil, and to percolation and subterranean drainage, which, as far as I know, has not been elsewhere noted. It is the fact that snow will lie in the forest more evenly and continuously than on the unprotected surface. This element of conservation not only increases the amount finally remaining for drainage, but also prevents the soil from freezing, keeping it open for percolation when the snows melt in spring.

In open fields the snows are not only apt to be dissipated by evaporation, but the soil is more apt to become incrusted with an impermeable surface stratum which would turn over the melting snow waters into surface drainage.

It is these snow waters, preserved to the subterranean drainage, which above all account for the continuity and equality of flow in springs far away from the catchment basin, the waters that fell in the winter and melted in the spring reappearing in summer.

A further element tending to increase the amounts of subterranean drainage waters lies in the retardation of the surface flow, by which the time is lengthened during which the soil may take up and filter through rain and snow waters.

The forest floor offers such impediments to surface flow not only in greater degree than any naked soil but than any other vegetation. An advantage over other kind of vegetation is also found in the deep penetration of the roots of trees, which increases the chance for percolation, while the more compact soil cover of a green sward would be rather opposing percolation. All that has been said regarding evaporation and transpiration within and without the forest needs also be kept in mind in the discussion of the amounts of drainwaters for underground disposal.

The conclusion, then, is, that in general a forest floor, although retaining much of the water in its upper strata, allows less water to run off superficially, and by rendering the soil more permeable larger amounts of water are turned into subterranean channels.

While this increase in drainage waters is the general tendency of the forest cover, geological stratification may be so favorable to drainage (deeply fissured vertical or tilted-up strata) that on the score of percolation at least the effect may become irrelevant, or it may be so unfavorable (horizontal unfissured strata) that the influence upon percolation may become practically of small value.

While underground, one part of the filtered water becomes stationary as soil moisture retained in the capillaries of the soil, and finally in part to be returned to the air by transpiration from the foliage and evaporation from the surface of the soil. The other part—the surplus above the water capacity of the soil—continues to filter through the soil, gathering into definite channels, collecting in beds or basins, and finally reappearing as springs. It is obvious that the first part can not be more than the water capacity of the entire soil layer, unless there be standing ground water which would replenish the loss by transpiration and evaporation, sustained by the soil moisture.

Now, by reasoning from the statements regarding the greater ease of percolation in soils kept granular under the protection of a forest-floor, as well as by the experiments regarding water conductivity and water capacity of soils under varying conditions, and regarding actual measurement of filtration waters from such soils, we are forced to admit that in general the quantities remaining for underground runs are not only larger in the first place, but remain so during their subterranean existence, suffering less loss by evaporation under the forest cover. This effect, especially apparent on shallow soils, will be more sensible the further away from the catchment basin the water reappears as a spring, that is, the longer the subterranean run.

FORMATION OF SPRINGS AND CONDITIONS AFFECTING THEIR FLOW.

Finally we come to a consideration of the conditions which determine the final reappearance of the underground drainage in the springs. The place where a spring appears is, of course, predicated in the first place by the structure and topography of the soil and rock strata. The question of the location of a spring is, therefore, a dynamical one, on which the soil cover can have but little influence. Yet even here, an indirect influence may be found in the amount of water to be drained, and in the looseness of the surface soil, both of which conditions would tend to produce more numerous outlets and a wider distribution of reappearing underground waters.

The following elementary explanation of the formation of springs may serve to show how geological conditions influence to a large extent the manner in which the waters falling on the watershed are distributed in underground channels, collected and discharged, and that, in spite of favorable forest conditions, a region may be poor in springs and that, without any disturbance of the forest cover, a change in the location or even in the run of springs may occur.

Springs.—A spring is water which has penetrated the soil and reappears collected on the surface. Springs are in most cases the beginnings of brooks and rivers. According to the manner in which the percolated water reaches the surface, springs may be classed as standing or running springs.

The standing or ground-water springs are such as collect water in some depression of the soil and overflow only as long as the water reaches the lower level of the outlet. Their formation is easily understood from the acccompanying figure (61), in which (1) represents a hillside of massive rock, continuing under the overlying strata at *a*. The latter consists of impermeable strata (2, 2) clay, loam, marl); above this a layer of gravel or coarse sand and rock material (3), and above this a stratum of soil (4), which at X is absent, leaving an open bowl where the gravel layer becomes visible. All the rain water falling on the plateau *o p* and on the slope *o a* running down, when arriving at the impenetrable strata near *b*, will be diverted into the gravel bed and spread in this, being prevented by the underlying impermeable strata from sinking. When sufficient water is supplied the water level rises until it appears at X, and if there is an outlet over the rim of the bowl and sufficient slope of the ground the spring begins to flow, forming, it may be, the beginning of a brook.

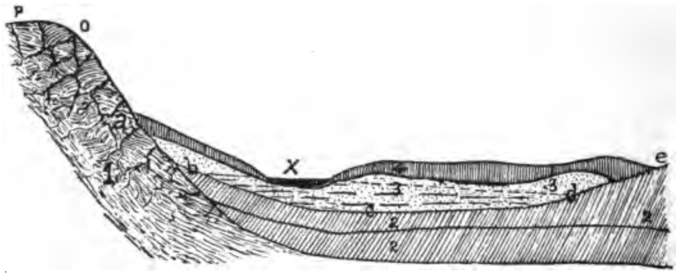


FIG. 61.—Standing or ground-water spring.

Such a standing or ground-water spring ceases to run if precipitation ceases for a length of time sufficient to reduce the water level below the outlet. Similar conditions can occur alongside of rivers when the seepage of the river supplies the water to a spring below the river level, and the level of these seepage waters rises and falls, of course, with the rise and fall of the river level.

Of running springs, there may be distinguished, according to the manner of their formation, three kinds—soil or surface springs, fissure springs, and cavern springs.

A surface spring originates when a more or less impermeable soil forms part of or lies near the upper soil stratum, allowing the water to enter only imperfectly and to an inconsiderable depth, and, passing through the looser parts of the soil, to collect and come to the surface at some point where the top soil is absent. These shallow-soil springs naturally vary quite sensibly, according to the physical conditions of the surface, and are dependent directly on the precipitation; dry up easily if it does not rain or if the soil is exposed to insolation and is deprived of shade; they are warm in summer and freeze out in winter. They are usually found in localities where the rock consists of easily disintegrated clay slates and sandstones, capped with a shallow layer of decomposed rock, or in the neighborhood of loam hills. An addition of broken rock and stones to the soil facilitates the penetration of the water and increases the comparative flow of these springs.

Whole districts along the foot of the Alps in Switzerland, Bavaria, Austria, and the Carpathians in Galicia, etc., have hardly any other kind of springs.

The second class, conveniently called "fissure" springs, originate from the waters which have deeply penetrated the soil and rock through the fissures, rents, and splits, or numberless cleavage strata of the upper rock formations, and ultimately reach a deeper lying inclined rock formation, which prevents further penetration and causes

the water to run along its upper plane until the formation somewhere comes to the surface and with it the collected water of the spring. These conditions are illustrated in the acccompanying cut (Fig. 62), in which *b c d e f* represents the upper fissured formations through which the rain and snow waters penetrate to the lower impermeable strata below the line *b f*, necessarily gravitating to point *f*, where the opportunity for discharging as a spring exists; a smaller spring might occur at *c*. Such conditions exist where lime or dolomite rocks overlie hard sandstones, compact clay

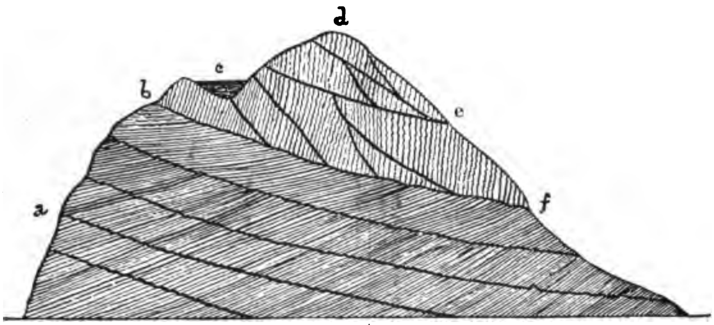


FIG. 62.—Fissure spring.

slates, or clay beds. These springs, as a rule, are much less dependent on the changes of precipitation and temperature; they are mostly continuous and even in their flow and their temperature.

The third class of the running springs may properly be called "cavern" springs, from the fact that while their waters are drained like those of the second class, they are first collected in some subterranean basins or caverns, and appear on the surface as overflow of these basins.

In the accompanying figure (63), *a b c* is the catchment basin, from which the various fissures conduct the water to *A*, overflowing at *X* into *B*, and from there overflowing and appearing at the surface at *Y*.

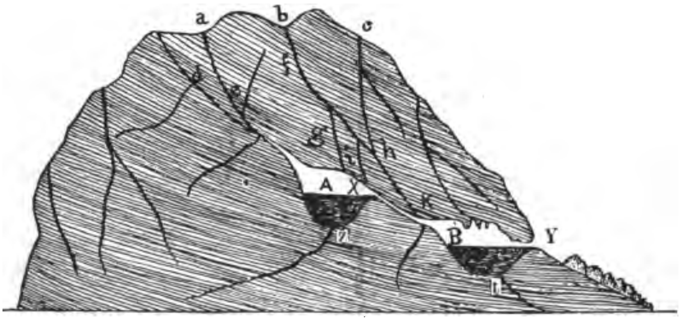


FIG. 63.—Cavern spring.

This kind of spring is found frequently in limestone formations, and since the waters of such often come from great distances from above their discharge at the surface, they are usually of very cold and even temperature; they are apt to run low when the soil is frozen and when precipitation is small; and their discharge is more or less intermittent. The obstruction of the old and opening of a new outlet by a fall of rocks at *X* and *Y*, and the widening of a formerly insignificant fissure at *z* or *t*, may reduce the flow or stop the original spring entirely, opening a new one in an entirely different part of the locality.

While we have here considered conditions under which springs are formed, there are also conditions under which their formation is excluded; such might be found in extended plains or low hill lands, with a compact, impermeable soil, which may give rise to pools and morasses, but not to springs. Plateaus of fissured limestone dolomites or of compact gneisses or granites may also be poor in springs, their waters sinking at once to such depths that no discharge is met in the immediate neighborhood of the catch-basin, or else shedding the water at once superficially.

The most direct influence of a forest cover upon the discharge would be noticeable on the surface springs, since in these the catchment area and the place of discharge lie close together, while the underground run is not only short, but lies near the surface, and hence experiences most sensibly the effect of the protection against evaporation which the forest cover offers. Deforestation here would no doubt reduce or cut off discharge entirely.

In cavern springs an influence could be exercised only in the indirect manner, by the increase of filtration over the catchment-basin. The same pertains to fissure springs, whose sources of supply are usually quite removed from evaporative influences, and only where these come nearer the surface or when the spring is only small, may the removal of the shade of forest cover reduce the outflow.

With reference to ground-water springs, which come to light at a considerable distance from the catchment-basin, the conditions of the latter as far as the influence, increase, and preservation of water supplies, and of the area over and under which the waters run collect, is of considerable importance, while the surface condition of the area within which the spring lies (*a e* of Fig. 61), if of impermeable strata, is of less consequence, except that a forest growth may lower the ground-water level by transpiration, should the water quantities furnished from the catchment-basin not be continuous and sufficient. If these strata consist of permeable soil, they would act as a second catchment-basin, and the effect of the soil cover upon the quantity of drain waters (precipitation, evaporation, and transpiration) would be directly noticeable. We have seen that the tendency of the forest cover—trees, foliage, litter, moss—is to change a certain amount of surface drainage into subterranean drainage, or, in other words, to reduce the surface waters where they have fallen. Eventually, however, the subterranean waters come to the surface again, and add their stores to the surface waters that are carried away in open runs, brooks, and rivers. Finally, then, all the water that falls on the catchment basin, except that which is returned to the atmosphere by transpiration or evaporation, becomes surface water; but the manner in which it runs off is the important point.

INFLUENCE OF FORESTS UPON SURFACE DRAINAGE.

Surface waters, like springs, may be considered from three points of view, namely their quantity, the course and manner of distribution, and finally their behavior when collected in rivers. All that has been said regarding the conditions of underground drainage has, of course, a bearing upon the quantity of surface drainage. The amount of surface run-off is the complement of the amount drained off by springs, and it follows that where surface drainage is the rule the supply to springs is scanty, and *vice versa.*

It is evident that the conditions for a superficial run-off are to be found, first, in the amount and nature of precipitation, and next in the soil and surface conditions. A violent rainstorm will naturally furnish more superficial run-off than when, the rain falling slowly, time is given for the soil to absorb it; a snow cover, fallen on frozen ground, is apt when melting to shed its water over the frozen surface without penetrating the soil.

Nature of soil and soil cover and topography determine, with equal amounts of water to dispose of, what the nature of the run-off will be. An impermeable soil takes up sufficient water to make it plastic and then sheds all additional water superficially; a permeable soil continues to take up water and conducts it into the depth. This difference of behavior must influence and determine largely the conditions of any river bed; for if it run for some distance through impermeable soil even insignificant rainfalls will rapidly collect and swell the river, while the permeable soil would have taken up and held all or parts of the precipitation and would only gradually have given it up.

The topography determines the rapidity of run-off and of collection. The more diversified the country—cut into dells, coves, rills, and furrows, steeper and less steep slopes—in the greater number of runs of unequal length is the water collected, while the less diversified the contour the more water must be carried off in each run. Yet where the diversity of configuration is accompanied by steep slopes the run-off may be so rapid that the valley river is filled more rapidly than the river of the open plains country with even slopes of moderate inclination.

Thus in some of the river valleys of West Virginia the watersheds are scooped out into such an array of coves, gashes, and water courses and minor watersheds, and so steep and rapid in descent that, in spite of the forest cover, a rainfall of a few days will induce a rapid rise of the rivers, while the same amount of rain will hardly wet the ground in a prairie country like Iowa.

As regards soil and surface conditions it is obvious that the less permeable the soil or soil cover the less the absorptive capacity of the same, and the fewer mechanical obstructions are met the more water runs off superficially.

RETARDATION OF THE WATERFLOW.

It is in the first place this mechanical obstruction which a forest floor more than most other kinds of vegetation offers, which changes the distribution in time of surface waters, that constitutes the forest an influential factor in water flow.

Direct measurements as to the difference in time which it takes for water to run off from watersheds of different conditions are difficult or almost impossible, because it would be necessary that not only the same amount of water should fall upon the two areas under comparison, but also that the topography, angles of slopes, and length be the same, and a ready means of measurement be found. In fact, the absorption and obstruction to surface flow acting in the same sense, it would be impossible, and for practical purposes also irrelevant, to credit each with its separate quota of influence. We shall, therefore, have to be content with general reasoning and more or less inaccurate observations to prove this retardation of surface drainage. But without any evidence furnished by experiments, we can at once understand that the surface run-off is impeded by any kind of mechanical obstruction, such as is offered by the vegetation of a meadow or of a forest.

The great number of inequalities which the forest floor offers, in addition to the trunks and stumps and fallen trees, forces the run-off to many detours, thus retarding its flow and its collection in the open runs and brooks.

The retardation in the waterflow begins even before the rain has reached the soil, for the leaf canopy catches and reëvaporates, as we have seen from 12 to 25 per cent of the total fall, and certainly retards the fall of the water to the ground, as can be readily observed; long after the rain has ceased the water keeps on dripping from the foliage. Thus, although most of the water reaches the ground at last, except in case of very light showers, yet the devious ways in which it reaches the soil makes the flow of water from a forest-covered hill longer in time than if the rain had fallen on a bare slope. As the result of a long-continued precipitation, it would be under the same conditions by an unforested slope, but this stage occurs in the forest later than on unforested soil and later still than on naked soil.

The great importance of the factor of time in surface drainage, both as regards dangers from freshets and erosion of soil, will be more readily appreciated when we remember that the dangerous waters in the mountains are generally of short duration.

A difference of 1,000 to 2,000 cubic feet of water per second from a square mile of watershed may often determine whether a dangerous flood is experienced or not. And since a square mile of moss-covered forest floor is capable of absorbing from 40,000,000 to 50,000,000 cubic feet in, say, ten minutes (a humus cover is capable of taking up 50 per cent of its own weight), nearly all of which the naked soil would give up some twelve to fifteen hours earlier, the surface conditions of the water-

shed must in many cases be determinative in the excesses of water flow in rivers.

This important fact should at least be recognized, that the surface conditions of the soil of a watershed are the only controllable factors in the problem.

Amount of precipitation, topography, and character of the soil are the practically unchangeable other conditions which determine the occurrence of freshets and floods. With a forest floor in good condition, small precipitations are apt to be absorbed readily and entirely prevented from running off superficially; with excessive rainfalls, topographical and soil conditions have eventually more influence than the forest floor; from steep declivities and an impermeable soil waters will be shed superficially in spite of and over the forest floor as soon as the latter is saturated at the surface.

Yet even so a difference in the run-off will be experienced by the fact that the well-protected forest soil prevents erosion, the formation of detritus and the carrying of débris into the runs and brooks below.

EXPERIENCE IN THE FRENCH ALPS.

By this protection of the soil the so-called torrential action of water is prevented, which, as the history of some departments in southern France has shown, is capable of devastating thousands of acres of fertile land by carrying the detritus into the valleys and depositing it there. At the same time the reforestation work of the French Government has also progressed far enough to furnish proof that the reclothing of the denuded hills is the practical remedy against these torrents.

Not only were the mountain sides themselves devastated and made useless by the destructive action of the water, but fertile farms for 200 miles from the source of the evil were ruined by the deposit of the débris and the population pauperized and driven out.

According to M. Demontzey, forest administrator of France, it was estimated, in 1866, that the area of denuded mountain lands needing reforestation was 2,964,000 acres. The Government has taken hold of the restoration of the most needing area, some 780,000 acres, on which so far some $10,000,000 have been expended, while private owners and communities have increased this expenditure for the repair of past follies to over $30,000,000, which is estimated to be about one-half of what is necessary.

How in our own country this erosive and destructive action of water is at work even in the hill country is thus graphically described by Mr. McGee, in speaking of the bad lands in the State of Mississippi:

> With the moral revolution of the early sixties came an industrial evolution; the planter was impoverished, his sons were slain, his slaves were liberated, and he was fain either to vacate the plantation or greatly to restrict his operations. So the cultivated acres were abandoned by thousands. Then the hills, no longer protected by the forest foliage, no longer bound by the forest roots, no longer guarded by the

balk and brush dam of the careful overseer, were attacked by raindrops and rain-born rivulets and gullied and channeled in all directions; each streamlet reached a hundred arms into the hills, each arm grasped with a hundred fingers a hundred shreds of soil, and as each shred was torn away the slope was steepened and the theft of the next storm made easier.

So, storm by storm and year by year, the old fields were invaded by gullies, gorges, ravines, and gulches, ever increasing in width and depth until whole hillsides were carved away, until the soil of a thousand years' growth melted into the streams, until the fair acres of ante-bellum days were converted by hundreds into bad lands, desolate and dreary as those of the Dakotas. Over much of the upland the traveler is never out of sight of glaring sand wastes where once were fruitful fields; his way lies sometimes in, sometimes between gullies and gorges—the "gulfs" of the blacks whose superstition they arouse, sometimes shadowed by foliage, but oftener exposed to the glare of the sun reflected from barren sands. Here the road winds through a gorge so steep that the sunlight scarcely enters, there it traverses a narrow crest of earth between chasms scores of feet deep in which he might be plunged by a single misstep. When the shower comes he may see the roadway rendered impassable, even obliterated, within a few minutes; always sees the falling waters accumulate as viscid mud torrents of brown or red, while the myriad miniature pinnacles and defiles before him are transformed by the beating raindrops and rushing rills so completely that when the sun shines again he may not recognize the nearer landscape.

This destruction is not confined to a single field nor to a single region, but extends over much of the upland. While the actual acreage of soil thus destroyed has not been measured, the traveler through the region on horseback daily sees thousands or tens of thousands of formerly fertile acres now barren sands; and it is probably within the truth to estimate that 10 per cent of upland Mississippi has been so far converted into bad lands as to be practically ruined for agriculture under existing commercial conditions, and that the annual loss in real estate exceeds the revenues from all sources. And all this havoc has been wrought within a quarter century. The processes, too, are cumulative; each year's rate of destruction is higher than the last.

The transformation of the fertile hills into sand wastes is not the sole injury. The sandy soil is carried into the valleys to bury the fields, invade the roadways, and convert the formerly rich bottom lands into treacherous quicksands when wet, blistering deserts when dry; hundreds of thousands of acres have thus been destroyed since the gullying of the hills began a quarter century ago. Moreover, in much of the upland the loss is not alone that of the soil, *i. e.*, the humus representing the constructive product of water-work and plant-work for thousands of years; the mantle of brown loam, most excellent of soil stuffs, is cut through and carried away by corrosion and sapping, leaving in its stead the inferior soil stuff of the Lafayette formation. In such cases the destruction is irremediable by human craft—the fine loam once removed can never be restored. The area from which this loam is already gone is appalling, and the rate of loss is increasing in a geometric proportion.

The formation of detritus and deposit in the river beds may also become the cause of dangerous floods in the larger streams for the amount of rock material and soil which the rivers carry is one of the most potent factors in their water flow.

Since this detritus is deposited wherever the velocity of the water sinks below that necessary to carry it, forming sand banks and rubbish heaps which obstruct and change the direction of the run, it plays quite an important part in shaping the bed of the river, besides in-

fluencing the whole system of dependent brooks and rivers. The nature and shape of the detritus—whether fine sand or earth, smaller or larger rock masses, stones, roundish, square, or flat—cause much difference; and this in turn depends upon many conditions, geological and climatical.

According to the nature of the rock from which it is derived, the detritus appears in different shapes, and again changes in form during its further transportation by the waters in different ways, and therefore exerts a varying influence upon the run. Thus the detritus, which appears in large plates or shales, is carried more easily than the square or round rocks; the former, even when deposited, hinders the flow of water between the plates but little, and therefore gives less cause for stow water than the heavy square rocks, which resist the transportation and obstruct the flow more effectually.

Sand and gravel detritus is easily carried, easily accumulated, and again with a new flood easily removed; it offers, therefore, little resistance to the flow of water, but becomes objectionable in filling the lower channels of rivers, etc.

Clay detritus, although easily carried, is apt to compact and cement the rock detritus together, and thus becomes one of the worst impediments of water flow and is the cause of the worst dangers from flood waters.

From these examples it is apparent that two rivers, although under similar conditions of rain fall, physical conditions of soil and topography, may yet show different behavior, according to varying character of the detritus.

As we have stated in the beginning of this chapter, the underground drainage gives to rivers their permanent régime, while the surface run off gives to them their rapid variations of stage.

According to whether a river is mainly supplied by surface waters that run in trackless courses and open runs over the slopes into its bed, or whether it is supplied by underground waters, its water conditions must follow a different course, fitful in the first, even in the second case. Few rivers depend on one of these sources of supply alone; most of them are supplied in the different parts of their course by both, so that a stream may begin as a torrent and later in its course find additional supplies from springs or ground waters—or the reverse may take place, being originated by a spring, it may have no other additions except from surface waters.

The greater the proportion of the supply by surface run-off the more liable to disturbances must be the flow. Finally in a larger river, like the Ohio or Mississippi the question of floods becomes still further complicated. For here not only the régimé of the main river, but also that of all its affluents and the topographic, stratigraphic, climatic, and surface conditions of their catchment basins become elements of dis-

turbance. Here the comparative lengths of the affluents alone may become all important, since the simultaneous or nonsimultaneous arrival of flood waters may determine the occurrence or nonoccurrence of high floods. As far as forest cover is concerned in such cases, deforestation in one of the side valleys and consequent rapid discharge may become an advantage for the water flow in the main river, by allowing its removal before the arrival of the flood waters of another affluent. In view of these considerations it would, therefore, be folly to assign to the condition of forest cover in the catchment basins an all determinative function. Nevertheless, in general the influence of favorable forest conditions in the catchment basin upon river flow can not be doubted, although it may become practically of no account in abnormal floods.

The first cause of abnormal floods is the occurrence of abnormal rainfalls or the sudden thawing of abnormal masses of snow. If the former occur after the soil has been saturated, or the latter when the soil remains frozen, the forest cover will be powerless to influence the run-off and will shed the water as rapidly almost as the open ground, although even the brief retardation of the confluence of water masses which the obstacles of a forest growth cause may be of moment.

But in its further course the drainage of this water, collected in the rivers is favorably influenced by the presence of the forest, it having prevented the formation and deposition of detritus in the river bed.

The beneficial influence of the forest in case of abnormal floods can then probably be claimed only in so far as it protects the slopes against abrasion and the formation of débris or detritus with which the upper head waters are filled, and which carried down into the rivers gives rise to sand banks and changes in the river bed which may increase the dangers of the next flood.

EXAMPLES OF THE INFLUENCE OF FORESTS ON WATERFLOW.

Besides the detail experiments, which are to furnish explanation of the physical laws upon which differences in water drainages occur, there are constantly accumulated experiences. Especially in France this question of forest influence on waterflow has been answered by practical demonstrations. To bring it, however, to a final solution, special hydrographic surveys and statistics, such as are now contemplated in Germany, will be necessary. A first attempt at such a work is the hydrographic description of the Rhine, a model work compiled by the agency of the various governments whose lands border on that river, published in 1889. This, however, was too comprehensive a field, and more detail measurements and observations would promise more striking results. The conclusions from this survey, and a more detailed one of the Hauensteiner Alp in the southern Black Forest mountains, are that the comparative absence of damage from high floods in this Alp country, when compared with neighboring valleys, may be ascribed to the forest

cover, occupying 51 per cent of its area, and the general observation is confirmed that the presence of well-kept large forest areas at the head waters in the mountains has a favorable influence upon the water stages in the water channels and per cent of erosion and formation of detritus to an appreciable extent.

One interesting detail hydrographic survey, which has in view to establish relation of forest cover to river, is published by Danckelman. It refers to the river Wupper, an affluent of the lower Rhine from the Rhenish state mountains. It was made in connection with the construction of a dam to regulate water supplies. Three catchment basins were under consideration, two of these, although containing 32 and 39 per cent woodland, are reported as devastated and especially robbed of their soil cover of litter and humus, the third containing near 50 per cent of well-kept dense forest.

From the detailed observations and measurements there was not observable any influence of forest conditions on the average daily and minimum flow, but in case of high water the daily flow was most decidedly influenced, namely, a diminution or retardation occurred in the well-wooded basin: in July, by 55 per cent; in August, by 34 per cent; in November, by 28 per cent; in March, by 21 per cent. It is stated in addition that the well-forested basin had a larger amount of rainfall and steeper slopes, a narrower valley, and was, therefore, comparatively more unfavorably situated.

An interesting note as to the amount of retardation which may be produced by the artificial means employed in the French Alps for regulation of waterflow, namely, forest-planting in connection with overflow dams, is given in M. Mathieu's work *Reboisement in France.*

The two basins of Faucon and Bourget were visited by a terrible downpour of rain of twenty-five minutes' duration. In the upper mountains there fell 42 millimeters, in the lower regions 12.3. The torrent of Faucon (which was in a devastated, deforested condition, but otherwise topographically similar to that of Bourget) was at once filled with flood waters which were estimated to consist of 60,000 cubic meters of water and 180,000 cubic meters of rock material or detritus, the flood subsiding in two hours.

In the torrent of Bourget, which had been reforested and corrected in its bed, a simple, somewhat turbulent run of water was observed, which at the overflow reached the height of 45 centimeters (18 inches) and lasted about three hours. The report continues:

These facts show the importance of the forest cover. Thanks to the dense forest growth planted, the flood waters, divided in numberless runs and retarded constantly in their movement over the declivities in the upper basin, arrive only successively and little by little in the main bed, instead of those formidable masses of water and débris which, rapidly agglomerated, rush into the channel; the brooks called to replace the torrents receive only pure water; flood waters flowing off gradually and made harmless by the regulation of the torrent bed and of the slopes.

In the department of L'Herault, in the Cevennes Mountains in southern France, the following calculation was made of the amount of water retained by the forest cover after a heavy storm.

The basin of Lampy, comprising 1,600 acres, of which more than 50 per cent are under forest, the rest in grass and field (6 per cent), rests on impermeable granite and quartz rock with a layer 2 feet deep of rich humus soil. All the water falling must pass into a reservoir formed by closing the valley with a dam which stores the water to a height of 51 feet. The reservoir, nearly 100 years old, has never needed to be dug out, which is mentioned as a sign of the absence of soil erosion. When full all the water must pass over the dam in an overflow race, which permits a tolerably exact calculation of the discharge of water from this reservoir. The discharge through pipes and overflow in one year (1860) amounted to 4,060,038 cubic meters, while from the record of one rain gauge at the reservoir situated, therefore, at the base of the elevations which rise to 1,000 feet above it, the rainfall was calculated 6,837,350 cubic meters. probably on account of the position of the gauge an understatement, showing, therefore, that not less than one-third and probably as much as one-half of the rainfall had been retained in the soil or evaporated.

On two days (July 28 and 29, 1863) there fell on this area of 1,600 acres, according to the rain gauge, 530,500 cub. m. of rain. Before the rain the reservoir was full to high-water mark, and the overflow, the only means of discharge open, had been delivering for days 3,936 m. or 45 liters per second, which must, therefore, be considered the natural discharge of the basin.

After the rain the water level rose 8 inches and the discharge was:

	Cubic meters.
July 29, morning and evening	30,504
30, morning and evening	28,864
31, morning and evening	7,872
Aug. 1, morning	7,872
2, evening	4,920
Total in five days	80,032

At the end of the fifth day the water level had returned to its former height and the discharge the next day was again 3,936 c. m., which it maintained for three months. If we deduct from the discharge of 80,032 c. m. the water that would have been discharged during these five days without the additional rainfall, namely (5 × 3,936=) 19,680, there remain 60,000 c. m. round, which without doubt were furnished by the two storms, and since the total fall had been at least 500,000 c. m. it follows that more than eight-ninths of the rain was absorbed and held by the soil to be delivered gradually.

In a neighboring basin, that of Salagou, of 16,761 acres extent, with just 10 per cent wooded, also on impermeable rock (permian), but the soil otherwise considerably washed and thin, observations could not be carried on with precision. But while the discharge of this much larger basin in ordinary times is calculated at not more than 20 to 25 liters per second, after a storm the discharge into the river is almost immediate and has been observed to rise to more than 600 c. m. per second.

Of examples in this country we may give the following as coming from good authorities and well substantiated.

In a report to the Chief of Engineers of the War Department in

regard to a survey of the Savannah River, made by order of Congress, it is said:

Reports upon the Savannah Valley and River at Augusta of about the year 1775 show the Savannah to have been a clear, rapid stream, full of excellent fish and subject to no sudden or marked changes of height. This was previous to the destruction of the forests and the opening of large tracts of land to the plow. Now the stream has become turbid; the fish, I am told, have nearly deserted the lower waters, and sudden and marked changes of the water level are the rule.

Maj. Charles W. Raymond, in a report to the Chief of Engineers, on the west branch of the Susquehanna River and the practicability of improving its navigation and of confining its waters, in times of great flood, to the general course of its channel, attributes as the principal cause of the excessive high and low stages of this river the progressive destruction of the forests from the mountain crests and slopes of its watershed, and in discussing the means of protecting the river valley from inundation in the future, says: "Most important of all, such forests as yet remain upon areas not valuable for cultivation, especially near the head waters and the upper slopes of the basin, should be protected."

The New York Forest Commission, speaking of floods in the Adirondack region and the influences of forests in relation to them, say:

In the uplands of the preserve there are many densely wooded tracts adjacent to others from which the forests have been stripped. The residents agree that in the former floods are unknown, while in the latter they are a yearly occurrence. Their appearance was coincident with the disappearance of the woods. It was then noticed that the bridges, which for many years had sufficed to span the streams during heavy rains, were no longer safe, and new ones with longer spans became a necessity.

They refer also to the effect of the removal of the forests in the Adirondack watersheds upon the navigation of the canals of the State and the whole system of inland commerce. They say:

With the clearing away of the forests and the burning of the forest floor came a failure of canal supply that necessitated the building of costly dams and reservoirs to replace the natural ones which the fire and ax had destroyed. The Mohawk River, which for years had fed the Erie Canal at Rome, failed to yield any longer a sufficient supply, whereupon the Black River was tapped at Forestport, and its whole volume at that point diverted southward to assist the Mohawk in its work.

The superintendent of public works of the State has also called public attention to this subject several times. In the report for 1882 he says:

The importance of the preservation of the woods in the Adirondack region in connection with the water supply of the canals can not be overestimated. With the continual cutting away of the forests and the burning of the forest floor, the decreasing water supply has become painfully apparent. Should this continue, the result on the canals would be disastrous.

Another interesting and impressive example of changes in conditions of water flow is given in connection with the Schuylkill River. During the last sixty or sixty-five years this river has shown a marked diminu-

tion in its minimum flow. In 1816 this flow was estimated at 500,000,000 gallons per day; in 1825, at 440,000,000; in 1867, at 400,000,000, and in 1874, at 245,000,000. In regard to this a commission of engineers say in their report in 1875:

This remarkable decrease, not being accompanied by any great change in the rainfall, nor probably in the total annual discharge of the river, is no doubt largely due to the destruction of the forests in the drainage area, whereby the conservative action of the woodland has been lost, and the rainfall is permitted to descend rapidly to the bed and pass off in a succession of freshets.

In the year 1881 the State of New Hampshire established a forest commission, who were instructed to inquire, among other matters relating to the forests, into "the effect, if any, produced by the destruction of our forests upon our rainfall, and consequently upon our ponds and streams." In their report, made in 1885, the commission presented a summary of the large number of replies to their inquiries. These replies came from all parts of the State. From the summary the following citations are made:

Beginning with the southern portion of the State, and with the town of Richmond, attention is called to a small stream there, which in 1865 furnished sufficient power for four sawmills nearly all the year, but which began to dry up with the more rapid removal of the timber occasioned by the introduction of steam as an auxiliary power. The water and the woods have disappeared together, and the same is the case in other portions of the town.

In Fitzwilliam and Rindge the same results have been reached all the more rapidly because of the nearer proximity of these towns to a market. Well-known trout streams, once abundantly stocked with fish, are now dry half of the year, and the treeless ground and naked rocks along their banks and about their sources are considered a sufficient explanation.

The chairman of the board of selectmen in Henniker, who has given much attention to the subject, is confident that the water in the Contocook River has decreased fully one-third within even twenty years, and that the tributaries have fallen off still more, many being nearly dry in the summer. During this period $75,000 worth of timber has been cut within this one town. In the surrounding towns, also, the timber has disappeared with equal rapidity, and the water supply has seriously decreased.

The report from Bow, which covers a period of fifty years, within which most of the timber has been cut off, and that from Hopkinton, which covers a period of sixty years, both tell the same story of naked hillsides and diminished streams.

At Hanover the Connecticut River for many years has been decreasing in volume, and with increasing rapidity the timber from its head waters has been floating by.

In Canaan sixty-five years ago there were nine or more mills of different kinds; abundant water power all the year around; no thought of reservoirs or double dams, or precautions against drought. Canaan street, now covered with a firm, dry sod, was laid out through a swamp, impassable but for the hummocks and fallen trees, while dense forests of giant trees covered the hills. The writer who furnishes the above facts, a native of the place, returning after an absence of thirty years, found the hills and rocks bare, the springs choked up, and the mills obliged to resort to steam power or lie idle.

The great mountain region of the State lies in contiguous parts of the counties of Grafton, Carroll, and Coos. The numberless streams originating in this region, protected by the primitive forest, might be thought to be beyond any disturbing causes, but such is not the case. The town of Littleton depends upon the Ammo-

noosuc for its water power, but three of its oldest citizens testify that this power has diminished one-third within fifty or sixty years. The mountain forests during this same period have been encroached upon as never before, and it is not surprising that so commonly these two facts are associated as cause and consequence.

Coos County contains more of the first growth of timber than any other portion of the State. In the midst of this region are the sources of the Connecticut, Androscoggin, Saco, and their many tributaries, and a diminished water supply at this point is felt throughout the course of these important streams. The report from Jefferson is that the older inhabitants agree that the streams are smaller than formerly. An intelligent observer at Berlin, on the Androscoggin River, makes the following important statements, covering a period of twenty-six years. Within a radius of 4 miles from his residence are eight streams or brooks and two ponds, and the water in each during the above period has materially diminished. As an illustration of the connection between the removal of the woods and this diminished supply, he adds that "six years ago he supplied his stock with water from what was then an unfailing brook, by means of an aqueduct which furnished 300 gallons per hour. Now that the trees along the stream have been destroyed by the woodman's ax and by forest fires, his water supply is cut short in summer by drought and in winter by frost. Hundreds of acres of timber have been cleared within these six years in the same vicinity."

At Lancaster, the county seat, on the Connecticut river, an old resident reports—

an alarming decrease in the water of the streams and springs during the past sixty years, and especially during the last twenty-five years, within which period the smaller timber also has been removed. Israel's River in his boyhood was a large mill stream 8 or 10 rods wide, with sufficient water to carry a very large amount of machinery the year round. Now it is an insignificant stream, with, from May to November, not more than half the water it had fifty years ago, and not more than two-thirds there was twenty-five years ago. Other streams have suffered in the same way, and the springs have, if possible, suffered more than the streams. Many, once thought to be never-failing, are now for long periods dry. That the cutting off the forests accounts very largely for this change he considers as sure as that effect follows cause, and the result is hastened by the reckless methods in use. Instead of cutting timber that is matured, everything is cut to the size of 5 or 6 inches in diameter, and what remains is cut into firewood or burned at once, leaving a dreary waste.

In conclusion the commissioners say:

While the statements given above prove beyond doubt the steady diminution of our water supply, and show what is the commonly received explanation of this state of things, a few of the towns heard from, and these mainly in the southern part of the State, report no very marked variation in the amount of water in ponds and streams for a considerable term of years, and an increase rather than a diminution in the amount of woodland. Much of this woodland, however, is the young growth, brush wood only, which can not for years protect the ground from the drying effects of sun and wind, as did the older woods; and, besides, from its relatively greater amount of foliage, evaporation proceeds all the more rapidly. That our wooded districts here and there are on the increase can not, however, alter the force of the facts which confirm the more commonly received opinion as to the general condition of things within our limits. If in any instances the decrease in water power has been checked or averted, it is all the more important to know how the result has been reached, that the same means may be used elsewhere. In every case this means has been connected with the preservation or restoration of the forests.

On one point there is no division of opinion. It is not in the open ground, but be-

neath the trees, that the moisture and the snow accumulate, and are slowly and surely supplied to the springs and streams, which then have a perennial flow. Let the same ground be deprived of its shade and this exposure to the sun hastens evaporation, and the rain and melting snow rapidly pass off through the water courses be fore any sufficient quantity can reach the permanent reservoirs under the surface. The snow on the exposed hillside may be swept off entirely by the wind; and even when any considerable portion remains, much will evaporate, and after all be lost to the soil and the springs. The soil itself is often washed off, and the exposed rocks given over to perpetual barrenness.

In confirmation of the conclusions of the New Hampshire forestry commission may be appropriately cited the statement made in the New Hampshire Geological Report (vol. 1, p. 124), that when in the central and southern portions of the State the hay crop has been cut short by drought, it has been known to be above the average in the northern part, even with less rainfall, and as a reason it is claimed that the forests in the northern section have secured a better distribution of the results of rainfall and melted snow.

R. W. Piper, in his Trees of America, gives this illustration as coming under his own observation:

Within about one-half mile of my residence there is a pond upon which mills have been standing for a long time, dating back, I believe, to the first settlement of the town. These have been kept in constant operation until about twenty or thirty years ago, when the supply of water began to fail. The pond owed its existence to a stream which has its source in the hills which stretch some miles to the south. Within the time mentioned these hills, which were clothed with a dense forest, have been almost entirely stripped of trees; and to the wonder and loss of the mill-owners, the water in the pond has failed, except in the season of freshets, and, what was never heard of before, the stream itself has been entirely dry. Within the last ten years a new growth of wood has sprung up on most of the land formerly occupied by the old forest, and now the water runs through the year, notwithstanding the drought of the last few years.

A gentleman in eastern Massachusetts makes the following statement: Having made a contract to supply an extensive nail factory with kegs in which to pack the nails made, he purchased a timber tract in southern Vermont, through which ran a stream. Upon this stream he erected a sawmill and began to cut the timber and make it into kegs. It was not long before the amount of water in the stream was lessened to such a degree that he was obliged to erect another mill below the first, and thus use the water a second time in order to maintain the requisite power for carrying on his business.

It is a well-known fact that the flow of water in the Hoosick and Housatonic rivers, in western Massachusetts, has become so irregular that the mill-owners on those streams have been obliged to make storage basins in which to hold the water of the spring floods for use in the summer, or else to equip their mills with auxiliary steam engines. The result is claimed to be due to extensive deforesting.

Mr. David Thompson, of Cincinnati, said to the American Association for the Advancement of Science, in 1881:

It is not unusual to find in many localities the beds of what were once important mill-streams, waterless, except when filled by sudden freshets, and in Ohio certain streams emptying into the lake, which were once declared navigable, will not now float a canoe. Previous to 1832 Capt. Delorac, of Hamilton, Ohio, annually sent a fleet of flatboats down the Big Miami River at the spring rise; but with the destruction of the forests along that river the rise became so uncertain that the enterprise was of necessity abandoned.

A farmer in Ulster County, N. Y., gives the following testimony on the subject before us. He had cut an acre or two of trees on an elevated portion of his farm. In giving the result he says:

My first loss was the drying up of a beautiful brook which had its source in my grove, and which ran through a number of fields, furnishing water for cattle while grazing. Five times the value of the wood I sold would have been refused for this stream. In the vicinity of the place where the timber stood the ground became dry during the summer. When rain fell it did not seem to be absorbed, the water ran down the hillsides, making great gullies and doing much damage, while the fields through which the brook flowed did not yield as good crops. I am now a strong believer in the value of woodlands on a farm.

A gentleman in Onondaga County states that the streams in that county have visibly failed since his boyhood, though he is not yet 40 years of age. There was at Conkling's Falls, he says, a grist and saw mill which in his youth had a plentiful supply of water. Then it gradually diminished. At first a spasmodic flow was marked; heavy freshets in spring, then low water in summer, until the water failed and it was necessary to run the mills by steam. So at Pratt's Falls, a few years ago the flow of water was abundant. The story was repeated there, violent freshets in spring, followed by the usual failure, until now, in summer, hardly a pailful runs over the falls. In this latter case there was formerly a swamp, some 5 or 6 miles above the falls, which has been reclaimed and all the trees and shrubs cut off. All these changes have occurred within fifteen years.

Ex-Governor Davis, of Maine, gives the following statement in regard to the effect of forest removal on the flow of streams, in a case with which he is well acquainted:

The Kenduskeag River empties into the Penobscot at Bangor. The stream rises some 30 miles from its mouth, one branch in the town of Dexter, and another in the town of Corinna. I am told that fifty or sixty years ago there was a continuous flow of water the year round in this stream, and at the town of Kenduskeag, 12 miles northeast of Bangor, were situated large lumber mills on both sides of the stream. The water-flow was sufficient to carry them the year round. But during the past half century the land along the shores of the stream has been cleared throughout the greater part of its course. The result is that we have heavy spring freshets, also heavy feshets in the fall, sometimes doing much damage. I recollect, a dozen years ago or more, when living in the town of Corinth, through which said stream flows, almost every bridge on the stream was carried away in the month of March. Now, after the spring freshet subsides, the water falls rapidly until it dwindles to a very small stream, not one-half the amount flowing during the summer months that did fifty years ago.

Mr. Abbot Kinney, of California, an intelligent observer, gives the following recent testimony in regard to a particular field on his estate:

This field was cleared of a dense brush growth, about 15 feet high, which, in California, is called chaparral. When first cleared the soil was quite dark in color and full of vegetable detritus.

For two years no special care was required to prevent gullies forming from the rains. The rain-holding power of the field has constantly diminished, cross furrows have now to be carefully prepared and maintained during the rainy season. A sharp rain now runs off without doing much good where it formerly soaked in. The dark color has gone and the soil is now a plain red. It packs hard now, after every rain, when formerly it did not pack at all, except in a pathway. On the edge of the bluffs where the brush was left the old conditions prevail. I was doing some work along these bluff edges and found that I could shovel the dirt easily after cutting off the brush, but on the cleared land adjoining where the plow had missed, near the edge, the ground was so hard as to require a pick.

In 1885 the Ohio State Forestry Bureau issued circulars to its correspondents throughout the State making inquiries in regard to the observed influence of clearing the forests upon water supply. The replies received are published in the first annual report of the bureau and will be found quite in harmony with the testimony above given.

Such reports as these can be multiplied from every section of our country, and, while there would always remain the onus of proof that the change of waterflow and forest conditions were in causal relation, it is difficult to conceive of any other causes for these experiences over so widespread an area, than the change of surface conditions due to deforestation, especially the burning of the forest floor. However questionable the position of forest cover as a climatic factor, its relation to waterflow and soil conditions is attested by experiences in all parts of the world.

IV.—NOTES ON THE SANITARY SIGNIFICANCE OF FORESTS.*

By B. E. Fernow.

The subject of the sanitary significance of forests has been recently reviewed by Dr. E. Ebermayer, the well-known physicist at Munich. Other investigators have also contributed new material toward the discussion of the subject. Especially the two Italians, Serafini and Arata, investigated the influence of forests on the quantity of micro-organisms in the air, and Dr. Puchner investigated the contents of carbonic acid in the atmosphere under varying conditions.

Ebermayer shows that the oxygen exhalation of a forest in proportion to the consumption by man is insignificant. He figures that a family of four persons would require for respiration, in the burning of the necessary fuel, the oxygen exhaled by 2½ acres of forest. The hygenic significance of ozone he doubts. Puchner shows that the air in the forest contains generally more carbonic acid than the open, due to decomposition of litter. On the other hand, Ebermayer shows the air in the forest soil to contain less carbonic acid than that in the field soil, three-fourths times less in winter and five-sixths times in summer; this is explained by differences in moisture conditions. But, like sea and mountain air, forest air is freer from injurious gases, dust particles, and bacteria. Furthermore, the shade and the processes of assimilation and transpiration have a cooling effect in summer, a warming effect in winter, hence extremes in temperature are checked. Protection against winds and extremes of temperature which the forest offers is cited as desirable for the location of sanitaria and finally a tribute is paid to psychic influence, and the hygienic significance of the forest is pronounced as scientifically established. But of much more importance than the air is shown the forest soil, especially since cholera, typhus,

*These notes are based on the following publications:

Dr. E. Ebermayer, in Wollny, 1890: (1) Hygienic significance of forest air and forest soil. (2) Experiments regarding the significance of humus as a soil constituent and influence of forest, different soils and soil covers on composition of the air in the soil.

Dr. H. Puchner: (1) Investigations of the carbonic acid contents of the atmosphere.

Serafini and Arata: (1) Intorno all 'azione dei boschi sui mikro organismi transportati dai venti.

yellow fever, and malaria are, according to Dr. Pettenkofer "soil diseases of miasmatic origin." In this connection a distribution must be kept in view between those organisms which are disease producers, pathogenic, and those which are more or less harmless parasites. The latter, Saprophytic bacteria, it must be kept in mind, thrive on decomposing vegetable and animal matter; but pathogenic bacteria thrive best on living organisms, although they occur also outside of them.

The conditions for the favorable development of the pathogenic bacteria Ebermayer discusses at great length. The facts are stated or established by him that the vegetable components of the forest soil contain less nutritive matter (albuminoid, potash, and phosphates and nitrates) for bacteria growth; that the temperature and moisture conditions are less favorable; that the sour humus of the forest soil is antagonistic to pathogenic bacteria; finally, that so far no pathogenic microbes have ever been found in forest soil, hence this soil may be called hygienically pure.

Only when upper soil strata dry out and a wind, forming dust, sweeps over them are microörganisms carried into the air; hence, with less air movement in the forest, we would expect fewer microbes in the forest air. This expectation is realized in the investigation of Serafini and Arata, who tabulate their countings of bacteria, divided into three classes—molds, liquefying, and nonliquefying bacteria for 40 successive days, from May 6 to July 8—and find, that with one exceptional day, one or two of these classes were always less numerous in the forest than on its outskirts and generally from twenty-three to twenty-eight times less.

With these detail investigations are in accord the general observations in India, where villages surrounded by forests are never visited by cholera, and troops are being withdrawn into forest stations in order to arrest the disease which it has been found is invited by removal of forests. Extensive moors, which exhibit similar unfavorable soil conditions, have been observed to give the same immunity from the disease. With regard to yellow fever the same observations have been made in our own country.

If it is considered, says Ebermayer, that the coma bacillus which produces cholera makes great demands in its nutrition and belongs to the most sensitive bacteria, especially sensitive against free acid, being destroyed by acid stomach juices, that when dry it dies quickly and is readily attacked by decay-producing bacteria, that it prospers best in a temperature of 86° F. to 194° F., and ceases to grow when the temperature sinks below 54° F., the protective influence of the forest is readily explained.

Malaria has been shown by Marchiafava and Celli not to be a bacterial disease, but to be produced by parasitic protozoa, called by these authors "plasmodia," which are formed in the red blood corpuscles and when inoculated upon healthy people produce the disease.

Although their exterior existence is unknown they probably also come from the soil, and probably, also, warmth or wet soil, periodically changing to dry in the upper strata, are the best conditions for their development. As long as the water covers the soil there is, therefore, no danger, which only begins with the recession of the same and the admission of air necessary for the development of the plasmodia, which accumulate then near the soil. Since they can not rise very high houses placed on hills within malarial regions or high above the ground are free from the disease.

The same reasons which make the forest conditions unfavorable to bacteria growth, namely reduced temperature and moister soil, with more ready drainage usually, as well as the absence of dust and winds raising the same and the filtration process shown by Serafina by which the bacteria coming from the outside are reduced in number, are also reasons for the observed beneficient effect of forest plantations in malarial districts, such as the Campagna Romana.

Finally, a word on the value of larger parks in cities. While they do not, according to these expositions, purify the air directly by the function of the leaves, as has been claimed, they certainly establish air currents that may bring fresher air to the ground; but their hygienic function consists mainly in reducing the temperature by their shade and in furnishing better drainage conditions of the soil and purifying the same by absorbing the results of decomposition from animal matter, and lastly by preventing or reducing at least dust and with it bacteria in the air, keeping it purer than it would otherwise be.

APPENDIX 1.

DETERMINATION OF THE TRUE AMOUNT OF PRECIPITATION AND ITS BEARING ON THEORIES OF FOREST INFLUENCES.

By CLEVELAND ABBE.

The accurate measurement of rainfall, or the confidence to be placed in the rainfall data that are being accumulated in such great quantities, is a matter of profound importance in climatology, in engineering, and even in storm predictions. This subject excites much consideration in the public mind, since the comparison of the ancient and present condition of Asia, Europe, and America leads to many forebodings as to our own future; it is therefore eminently worthy of full treatment and critical discussion. We must be satisfied as to the degree of reliability of our data before we use them in attempting to elucidate such queries as are suggested by thoughtful men and such as were in fact discussed at a recent symposium of the Philosophical Society at Washington upon the question "Do forests affect rainfall?"

On that occasion extensive statistics were presented by several members of that society, but it seemed to me that certain other fundamental questions which are discussed in this paper must be considered if we desire to get at the exact truth in regard to this matter.

The question, "Whether forests affect rainfall?" can apparently be attacked from several sides. Some are satisfied to appeal to deductive reasoning, thereby proving that the forests ought to affect rainfall, and their arguments have much plausibility; others are satisfied to appeal to the historical evidence and quote the dried-up streams of Europe, Asia and America, and the deserts that were once gardens. But the instrumental meteorologist and the observer who knows that rain gauges have been carefully observed here and there for the past 300 years, or since the first gauges were used by Leonardo da Vinci, still naturally look to the records of the many stations that are accessible to us and expect these to give a very definite statistical answer that can be relied on quantitatively as well as qualitatively.

Such rainfall records must be the ultimate test of the truth of any hypothesis, but the question is one of considerable difficulty since we have to determine a small quantity by means of observations that may be liable to large errors, and it is necessary to be on our guard against fallacious reasoning and against the liability to

draw conclusions finer than the data will warrant. To this end the law of errors or the calculus of probabilities must be appealed to. My present study relates principally to subjects of fundamental importance, namely, the accuracy of the individual statistics and the variability of distribution of rainfall chronologically and geographically.

RELATION OF PATTERN AND ALTITUDE OF GAUGES TO ACCURACY OF RAINFALL MEASUREMENTS.

With regard to the accuracy of rainfall measurements viewed simply as comparable data, two matters have been studied experimentally, namely, the size and style of the gauge and the altitude above ground. With regard to size it is satisfactorily shown that no error of more than 1 per cent systematically attaches to gauges of the ordinary forms and of diameters anywhere between 4 and 44 inches. With regard to the altitude it must be conceded that for a hundred years it has been known in a general way that observations by gauges at various heights above the ground are not comparable with each other. The remarkable influence of altitude was first brought to the attention of the learned world by Heberden, who, in a memoir in the transactions of the Royal Society of London, in 1769, stated that a gauge on Westminster Abbey over 150 feet above the ground caught less than half as much as a gauge at the ground. Since his day numerous others have instituted similar observations in their respective localities. Usually they have been satisfied with observing only one or two elevated gauges, but of late years, in order to fully elucidate the subject, more elaborate measurements have been made; thus Phillips and Gray, at York, England, have observed at eight different altitudes including the gauge on the tower of York Minster.

Bache, at Philadelphia, observed four gauges on top of a square tower, and four others on poles above them; Col. Ward, at Calne House, Wiltshire, observed ten pairs of gauges at elevations of 20 feet or less, each pair consisting of an 8-inch and a 5-inch gauge; Bates, at Castleton Moor, similarly observed ten pairs of gauges; Chrimes, at Rotherham Reservoir, six gauges, at elevations of 25 feet or less; (——?) at Hawsker, four 3-inch gauges, at altitudes of 10 feet or less; Wild, at St. Petersburg, six 10-inch gauges, at altitudes of 5 meters or less, and one at an altitude of 25 meters. A very laborious series of six or eight gauges at altitudes of 40 feet or less has, to my knowledge, been carried on for some years by Fitzgerald, at Chestnut Hill, near Boston, but the results are not yet published.

It will be seen, therefore, that abundant observational data are at hand for the elucidation of the peculiarities of the rain gauge, and the results that can be deduced from such data command our immediate attention. Whatever mystery has hitherto attached to the undoubted fact that elevated gauges catch less rain is now fully explained away. This phenomenon is of the nature of an error in the rain gauge depending upon the force of the wind that strikes it, and as will be seen, now that the knowledge of the source of error has been established, the method of correcting or preventing it becomes simple.

It will be remembered that Benjamin Franklin, upon reading Heberden's memoir, at once, in 1771, in a letter to Percival explained his results by the hypothesis that falling cold rain drops condense the moisture they meet with in the warmer lower strata, and that Phillips, in 1834, independently revived this hypothesis as explaining the increase of rainfall. A much truer explanation had been suggested by Meikle, in the Annals of Philosophy for 1819, and by Boace (Annals of Philosophy, 1822), to the effect that the deficiency is due to the velocity of the wind and to the fact that the gauge stands as an obstacle to the wind; also Howard showed that the strength of the wind affected the higher gauge. But these minor notices seem to have produced but little effect among meteorologists, and it remains for W. B. Jevons, Phil. Mag., 1861, vol. XXII, to demonstrate that the Franklin-Phillips hypothesis

was highly unsatisfactory, and in fact impossible, and that the true reason of diminution of apparent rainfall with the height of gauge is the influence of eddies of wind around the building and the mouth of the gauge. This explanation had, however, been also quite clearly pointed out by Prof. Bache, who had shown that eddies around the top of the tower affected the distribution of the rainfall on the tower. Alexander Dallas Bache and Joseph Henry were intimately associated in their scientific work as early as 1835 (and especially after Henry came to Washington, in 1847,) and the latter had adopted that which is now called Jevon's explanation, although as we have seen it was first given by Meikle, 1819, and subsequently independently arrived at by many others. This theory was definitely adopted and disseminated by Henry at least as early as 1853 in connection with his instructions to Smithsonian observers.

The essence of this explanation may be stated thus: In the case of ordinary rainfalls we invariably have the air full of large and small drops, including the finer particles that constitute a drizzling mist and the fragments of drops that are broken up by spattering. All these are descending with various velocities which, according to Stokes, depend on their size and density and the viscous resistance of the air; the particles of hail descend even faster than drops of water and the flakes of snow descend slower than ordinary drops. Now when the wind strikes an obstacle the deflected currents on all sides of the obstacle move past the latter more rapidly; therefore, the open mouth of the rain gauge has above it an invisible layer of air whose horizontal motion is more rapid than that of the wind a little distance higher up. Of the falling raindrops the larger ones may descend with a rapidity sufficient to penetrate this swiftly moving layer, but the slower falling drops will be carried over to the leeward of the gauge, and failing to enter it will miss being counted as rainfall, although they go on to the ground near by. Evidently the stronger the wind the larger will be the proportion of small drops that are carried past the gauge; or again, the larger the proportion of small drops and light flakes of snow that constitute a given shower, the more a gauge will lose for a given velocity of the wind. In brief, the loss will depend both upon the velocity of the wind and the velocity of the descent of the precipitation; therefore, a gauge will in general catch less, in winter than in summer—less in a climate where light, fine rains occur than where the rains are composed of larger, heavier drops; less in a country or in a season of strong winds than of feeble winds; less when exposed to the full force of the wind by being elevated on a post than when exposed to the feebler winds near the ground.

The action of the wind in blowing the precipitation over to the leeward of the gauge depends on velocity rather than on the square of the velocity of the wind and of the raindrop, and it is aggravated by the formation of whirls or eddies within the gauge itself by reason of which light and dry snowflakes are even whirled out of the gauge after being once caught in it. Similar remarks apply to the rainfall on the top of a large square building with a flat or depressed roof; not only does the top as a whole receive less than an equal area at the ground, but the distribution of rainfall on the roof is such that the least rain falls on the windward portion and the most on the portion to leeward, while somewhere on the roof will be found a region whose average rainfall coincides with that on the ground. But the location of this region will vary with the direction and strength of the wind and the quality of the precipitation, so that we have but little assurance that any single rain gauge on the roof will represent the rainfall on the ground.

An interesting illustration of this action of the wind has been noted by me in the case of several gauges established in a cluster in a sandy region. The gauges sat on the ground; their mouths were 2 or 3 feet above the surface, and being cylindrical they offered considerable resistance to the wind. The windward gauges caught less rain than the leeward, but they also caught more sand, showing that the strong winds which carried the light raindrops on beyond also stirred up the light surface

sand and were just able to drop the sand into the windward gauges while carrying the rain on to the leeward gauge. In accordance with the preceding explanation all observations everywhere show that the higher gauges have the larger deficit in rain catch and still larger deficits in the snow catch, and that both deficits increase with the wind.

Mordecai states (Journal Franklin Institute, 1838, vol. XXII, p. 37) that he arranged his observations at Frankfort Arsenal to show the rain catch at the ground and on the tower 52 feet high according to the force of the wind as estimated by him on the scale 0 to 10 as used by him, and found the deficit of the tower gauge to be 0 per cent for calms and light winds, but increasing steadily up to 36 per cent for a wind of force 8.

Börnstein (Met. Zeit. Oct. 1884) arranges the catch in protected and unprotected gauges according to the velocity of the wind, and for seven months of observation obtained the following deficits in millimeters, to which I add the same converted into percentages on the assumption that the protected gauge is practically equivalent to the pit gauge. This assumption, although it is not quite correct, will not much change our results:

TABLE I.

Wind force—0 to 12.	Number of days.	Protected gauge catch.	Unprotected gauge catch.	Unprotected gauge deficit.	Unprotected gauge deficit.
		Mm.	*Mm.*	*Mm.*	*Per cent.*
0	5	3.30	3.06	0.24	7
1	37	88.34	81.44	6.90	8
2	26	70.40	63.80	6.60	9
3	15	36.62	29.89	6.73	18
4	15	43.45	39.57	3.88	8
5	1	2.50	1.50	1	40
6	1	1.76	1.38	0.38	22

The distinction between the effect of the winds in heavy rains and fine rains is very clearly brought out by Börnstein's classification of the catch on twenty-six days of fine rain and forty-three days of heavier rains; the percentages are as shown in the following table:

TABLE II.

Wind force.	43 heavy rains.		26 fine rains.	
	No. of days.	Deficit.	No. of days.	Deficit.
		Per cent.		*Per cent.*
0	....	....	4	23
1	17	6	8	25
2	13	13	6	18
3	7	14	6	46
4	6	17	2	52

Although all these preceding data, both by Mordecai and Börnstein, are limited in quantity, yet they conspire to show uniformly the same effect of the wind that is shown in an exaggerated scale when the ordinary gauge is used to catch snowfall. Similar results based on a somewhat larger series of observations are published by Wild (Repertorium for Met., vol. IX), as shown in the following Table III, which gives the percentage of catch during winter's snow and summer's rain separately for several altitudes and wind velocities:

TABLE III.

Altitude	Low wind velocities (2 to 5 meters per second).		High velocities (6 to 9 meters per second).	
	Rainfall (Apr.-Oct.).	Snowfall (Nov.-Dec.).	Rainfall (Apr.-Oct.).	Snowfall (Jan.-Mar.).
Meters.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0	100	100	100	100
1	95	89	94	80
2	92	86	84	82
25	81	26	56	16

These tables conclusively show the large influence of the wind on the catch of the rain, to say nothing of its influence on the catch of the snow. It is therefore evident that the annual rain precipitation as shown by gauges at various heights, although always diminishing with the altitude, will diminish in different ratios according to the peculiarities of the precipitation and the wind in that locality.

Without attempting to go into special refinements it will be sufficient for the present to study the annual catch as recorded at numerous stations. I have therefore in the following Table IV arranged the results quoted by Wild (Repertorium vol. IX, 1885) and some others that have been published elsewhere. This table begins with the results of observations made at low altitudes and of these I have taken the average of all observations made for four years at Calne, three years at Castleton, eight years at Rotherham, and ten years at St. Petersburg with gauges of from 5 to 10 inches diameter. I have omitted the observations for two years at Hawsker with 3-inch gauges, because of the shortness of the series and the smallness of the gauge, which latter point has slightly exaggerated the percentage of loss. The combined result therefore for the 4 longer series is to show that for gauges of such size and construction as are generally used in the weather bureaus of the present day and for the average wind and snow or rain that occurs at these stations (which are in fact fair representatives of the northern portion of the temperate zone) the catch of rainfall diminishes with height of gauge, as shown by the percentage in the last column and in which, of course, the catch of the normal pit gauge is adopted as the standard.

TABLE IV.

Location.		No. of years.	Altitude.	Relative catch.
			Meters.	*Per cent.*
			0	100
			1	90
Calne	5-inch and 8-inch gauges	4	2	88
Castleton	5-inch and 8-inch gauges	3	3	86
Rotherham	5-inch gauges	8	4	85
St. Petersburg	10-inch gauges	10	5	85
			6	84
London: Westminister Abbey		1	9.1	77
Emden		2	11	72
St. Petersburg, Central Observatory		1	13	68
York: Museum		3	13	80
Calcutta: Alipore Observatory		7	15	87
Woodside: Walton on Thames		1	15	73
Philadelphia: Frankfort Arsenal		3	16	95
Sheerness: Waterworks		3	21	52
Whitehaven: St. James' Church		10	24	66
St. Petersburg, Central Observatory		10	25	59
Paris: Astronomical Observatory		40	27	81
Dublin: Monkstown		6	27	64
Oxford: Radcliffe Observatory		8	34	59
Copenhagen: Observatory		4	36	67
London: Westminster Abbey		1	46	52
Chester: Leadworks		2	49	61
Wolverhampton: Waterworks		3	55	69
York: Minster		3	65	60
Boston: St. Botolph Church		2	79	47

For gauges higher than 6 meters this table gives the results of the individual localities. If we consider the individual figures in the latter part of this table it would seem that the diminution of rainfall with elevation of gauge is decided, but irregular; but it is proper to collect the data into a few mean values as shown in the following table, in which the three higher groups may be considered to represent the average conditions of the precipitation in the temperate zone quite as fairly as do those of the lower altitudes:

TABLE V.

Group.	No. of stations.	Altitude.	Observed deficit.	Square root of altitude.	Computed deficit.	Obs.-Comp. deficit.
		Meters.	*Per cent.*			
1	4	0	0	0.0	0	0
2	4	1	10	1.0	6	+4
3	4	2	12	1.41	8	+4
4	4	3	14	1.73	10	+4
5	4	4	15	2.00	12	+3
6	4	5	15	2.24	14	+1
7	4	6	16	2.45	15	+1
8	7	13	21	3.61	22	−1
9	7	28	36	5.29	32	+4
10	5	59	42	7.68	46	−4

If we may assume that on the average of the years and of the localities thus grouped together there is a fairly uniform average quality of precipitation, we should expect the deficiency at each altitude to have some definite relation to the velocity of the wind, and it emphasizes our conviction that the wind is the principal factor in bringing about this deficit when we find that these normal percentages are fairly represented by the simple formula: Deficit=6 per cent of the square root of the altitude expressed in meters. The adoption of the simple square root of the altitude is of course suggested by the well-known studies of Stevenson and Archibald, from which I infer that for these low altitudes the square root is a satisfactory approximation to the rate of increase of wind with altitude, while for much higher altitudes the one-fourth or other power might be preferable. The constant factor, 6 per cent, that enters this formula will of course not be understood as applicable to other gauges or velocities or qualities of precipitation than those included in the above table, but the close agreement of the computed percentages of deficiency shows that we appear to be on the right track, and that some method must be devised by which to free rainfall measures from the influence of the wind at the mouth of the gauge. We see, in fact, that the simple wind-gauge which we have trusted so long is liable to systematic error, whose magnitude is really enormous as compared with the small errors that we ordinarily investigate in connection with thermometers, barometers, and anemometers.

ELIMINATION OF ERRORS OF THE RAIN GAUGE.

Two methods are open to us by which to eliminate this error of the rain gauge. One is instrumental, the other observational.

Instrumental methods.—As before said, Profs. Bache and Henry seem, from their own observations, to have clearly apprehended the nature of the error with which the gauge is affected, and the latter was quick to suggest the remedy, namely, to so construct a gauge that it shall closely imitate the conditions of the normal exposure, or that of a gauge whose mouth is on a level with the ground, and which is, therefore, not covered over by the disturbing swift currents and eddies. The records of the Smithsonian show that Henry caused numerous experiments on this subject to be conducted after he and Espy, in 1848, inaugurated the Smithsonian system of meteorological observers. In the second volume of Henry's collected writings, the reader can easily consult his discussion of the erroneous explanations and his own correct ex-

planation of the phenomenon, and at page 262 will be found Henry's suggestion of "the shielded gauge." This shielded gauge was an ordinary small cylindrical gauge; a few inches below the mouth of this gauge a horizontal circular plate of tin 4 or 5 inches wide was soldered to it like the rim of an inverted hat; by this means he hoped to ward off the disturbing eddies which would necessarily be formed almost wholly beneath the flat rim and therefore harmless.

Although Henry's shielded gauge was described at least as early as 1853, yet I have not found as yet any records or observations made with it, though such probably exist, as Henry's suggestion was widely distributed among the Smithsonian observers.

In 1878 Prof. Nipher, of St. Louis, published the first results of his observations with his own shielded gauge, as independently invented by him. He surrounds the upper portion of the gauge by an umbelliform screen made of wire gauze; the falling rain strikes on this and breaks up, and falls down to the ground without spattering into the mouth of the gauge at the center, while the gauze sufficiently breaks up the wind currents to maintain a normal condition of the air at the mouth of the gauge. Nipher's own experiments with this gauge showed that its catch at a height of 118 feet above the ground was nearly the same as that of the ground gauge itself.

The invention of the shielded gauge gives us the required instrumental solution of our problem. Of late years Börnstein in Berlin and Wild in St. Petersburg have experimented very largely with Nipher's shielded gauge and have reported in its favor. Hellmann, during 1887, also observed with a Nipher gauge, and finds the effect of the shielding to be very favorable, but not so much so as to make it quite equal to the ground gauge.

The good accomplished by the shields adopted by Henry, or by Nipher, can also be largely attained by a simple system of protection from wind. By "a protected gauge" I mean an ordinary gauge whose mouth is a few feet above the ground, and which is surrounded at a distance of a few feet by a fence or screen separate from the gauge, and whose top is a little above the mouth of the gauge. The protecting fence is therefore so arranged that it diminishes the wind at the mouth of the gauge without itself introducing new and violent injurious eddies. Both Börnstein, Wild, and Hellmann have experimented with such protected gauges, the protecting fence being so constructed that the angular altitude of the top of the fence as seen from the mouth of the gauge is between 20 and 30 degrees. The catch of the gauge thus protected always exceeds that of the free gauge, so that the correction to reduce it to the ground gauge is comparatively quite small, the deficit being reduced from 25 per cent down to 3 or 4.

Hellmann has also made the following interesting experiment: The roof of the Academy of Architecture in Berlin, where the Royal Prussian Meteorological Institute is temporarily domiciled, covers about 50 meters square, and is not merely flat, but depressed considerably below the rampart walls of the building; it, therefore, constitutes a grand protection to any gauge placed near the center of the roof, and accordingly Hellmann finds that in this location gauges catch more than anywhere else on the roof or the ramparts, and but little less than a gauge on the ground. His conclusion is that the Nipher, or similar protection, can nearly, but still only partly, annul the injurious influences of strong winds on the catch of the gauge.

The reduction or correction of rainfall for altitude, as it has hitherto been called, is therefore really a correction or reduction of the readings of the rain gauge for an instrumental error due to the wind.

Observational methods.—As an observational method of obtaining the true rainfall from the gauge reading, and if it is impracticable to establish a normal pit gauge in a good location, or if it be desired to determine approximately the correction to be applied to past records obtained from a gauge that still remains in the former place, the following arrangement offers a fair approximation.

If the present gauge has been standing in an open field at a few feet elevation,

place two or more *similar gauges* near it, and similarly located as far as obstacles are concerned, except only that one of these is to be decidedly lower than the old one and the other decidedly higher. From a comparison of the simultaneous records of any two gauges and their altitudes, we should for each separate rainfall, rather than for the monthly and annual sums, deduce the normal rainfall by the solution of two or more equations of the form:

Observed catch of gauge $= (1 - x\sqrt{\text{altitude}}) \times$ (desired catch of normal pit gauge).

Where x is the unknown special coefficient of deficiency due to wind at that altitude—that is to say, having two gauge catches, c_1 and c_2 for the two altitudes H_1 and H_2—we obtain the true rainfall (R) by the formulæ:

$$c_1 = (1 - x\sqrt{H_1})\,R$$
$$c_2 = (1 - x\sqrt{H_2})\,R$$

whence

$$R = \frac{c_1\sqrt{H_2} - c_2\sqrt{H_1}}{\sqrt{H_2} - \sqrt{H_1}} = c_1 + \frac{1}{\sqrt{\frac{H_2}{H_1}} - 1}(c_1 - c\ ) = c_1 + n\,(c_1 - c_2).$$

If c_1 and H_1 relate to the lower gauge we shall generally have $c_1 > c_2$ and $H_1 < H_2$ and the coefficient n will be a positive fraction, whose value is given in the following table for such combinations of units as may easily occur in practice.

TABLE VI.

Altitude of upper gauge.	Values of n for altitudes of lower gauge				
	1	2	3	4	5
2	2.414				
3	1.366	4.450			
4	1.000	2.414	6.469		
5	0.828	1.721	3.438	8.474	
6	0.689	1.366	2.414	4.450	10.485

If the present gauge is located upon the top of a building, perhaps the best that can be done to study the accuracy of its records is to locate other similar gauges so as to get the average rainfall over the whole roof at the same uniform altitude; the next best would be to establish a standard protected or shielded gauge as high as practicable above the roof.

If a new observing station is to be started then a single shielded or protected gauge is better than a single unprotected one; but two more shielded gauges at different altitudes afford the means of calculating the correction for wind which will, of course, be quite small for this style of gauge.

VARIATIONS IN GEOGRAPHICAL DISTRIBUTION OF RAINFALL.

By the combination of records from widely separated rainfall stations we ordinarily seek to determine the uniformity or irregularity of rainfall as to its geographical distribution. The study of horizontal distribution of rain should be first made by means of simultaneous observations at many stations within a small region. The most instructive work of this kind that I know of is that just now being carried on by Hellmann in the "experimental rainfall field" of the Royal Prussian Meteorological Institution. This institution was in 1884 officially transferred from the bureau of statistics, where it had been organized by Mahlmann and Dove, over to the bureau of religion, education, and medicine, where it is now intimately connected with all the scientific and educational work in Berlin and is under the directorship

of Prof. W. von Bezold. The experimental rain field really consists of the city of Berlin and the country around especially to the westward, embracing a region of about 15 kilometers square, within which are located Berlin, Spandau, and Potsdam. The forests on the westward, the intermediate gardens and fields, the valley of the river Spree, and the city of Berlin, offer a great variety of surfaces but without any mountains or hills. The average height of the ground above sea level is scarcely 50 meters, the average distance of the gauges from each other, namely, the mean of all possible combinations is about 4.5 kilometers, the maximum distance being 11 and the minimum 0.5.

Within this area Hellmann has twenty-one stations, some of which represent several gauges. His work began in 1884, and he adopted as the standard height of the mouth of the gauge 1.07 meters above the ground. I have selected for study the eleven stations for which complete records for 1886-'87 are given in Hellmann's Reports. The accompanying Table VII shows the rainfall for each station for each year and the departures of each station from the annual mean of the eleven. From these departures we get the probable error of any one annual rainfall as plus or minus 6 per cent of its own value. That is to say, assuming that the same quantity of rain and snow fell uniformly over the whole of this small region and that the gauges, if unaffected by any error, should therefore agree among themselves perfectly, then their failure to do so is such that it is an even chance that any given rainfall is discordant from the average by plus or minus 6 per cent. At first Hellmann suggested that the records of stations 1, 2, 3, and 4, which were in the open land east of the forests showed that less precipitation fell there than over the forests, affording an argument for the idea that the forest attracted an extra amount of rain; but of the other stations there were also some that were protected by the forests, and next year all of these reported large rainfalls. Now all of those gauges were at a standard height in open regions such that only the variations in wind proper or in the currents induced by neighboring obstacles could conceivably affect the catch of the gauge; moreover the differences between the stations were greatest in the winter and least in the summer months and all the study of the configuration of the ground around the stations tends to show that the differences in the catches of the gauges were due to the irregularities of horizontal distribution of the strength of the wind as influenced by the surroundings. In other words instead of studying the geographical or horizontal distribution of the total annual rainfall it was safe to assume that that had been uniform for each year over this small area, and that we are studying simply the horizontal distribution of a deficiency in catch or a rain-gauge error due to very local winds at the mouths of the gauges.

TABLE VII.

Station, Hellmann's number.	Observed precipitation.		Departures.			
	1886.	1887.	1886.	1887.	1886.	1887.
	mm.	*mm.*	*mm.*	*mm.*	*Per ct.*	*Per ct.*
1	394	514	30	4	7	1
2	363	507	61	11	14	2
3	387	524	37	6	9	2
4	388	505	36	13	9	2
6	435	492	11	26	3	1
7	438	536	14	18	3	1
8	462	549	38	31	9	2
9	462	509	38	9	9	2
10	473	536	49	18	12	2
12	444	516	20	2	5	1
14	422	516	2	2	0	0
Mean	424	518	336	140		

This conclusion is confirmed by examining the records in the summer months separately from those in the winter. Local showers are frequent during the summer

and the irregularities in horizontal distribution are presumptively greatest at that time. During the winter the extended layers of clouds give us no *a priori* reason to expect large irregularities in the geographical distribution of snow fall and rain. Hellmann's records show that the geographical irregularities in the catch of his gauges is really least in summer and greatest in winter, thus confirming our convictions that on the average of the year the precipitation is uniformly distributed and the variations in catch depend on the geographical distribution of the wind at the gauges during the fall of rain and snow.

The eleven gauges here selected from Hellmann's data were unprotected and uniformly 1.07 meters above ground, and it is evident that they would not have necessarily shown a similar discrepancy of 6 per cent among themselves had they been placed at some other altitude. As the absolute deficits of each gauge increase like the wind with the square root of the altitude, so also should the apparent irregularities in geographical distribution. But this rule should not be so far stretched as to assume that gauges at the ground surface would therefore show no irregularities in the horizontal distribution of rain, the fact being that there is even for them an outstanding uncertainty of 2 per cent, which is the total combined effect of all the irregularities of measurement and the drifting of snow or rain.

In general, then, we conclude that in the case of a number of gauges placed within a few miles of each other, and of which we know nothing as to the height and exposure, except that in general the observers have placed them in fairly open situations, there is no reason to give a preference to the reports of one gauge rather than that of another, since if the observers are equally reliable the irregularities of catch are likely to far exceed the errors of careful observers. Again, the probable error of 6 per cent, due to unobserved and uncontrollable irregularities in the action of the wind on these ordinary cylindrical gauges located 1.07 meters above the ground, indicates the utmost limit to which any attempt at refinement in drawing annual isohyetal lines should be carried at present, at least in the climates such as that of Berlin, and until the data are corrected for wind effects. Finally, any attempt to deduce from such gauges the relative rainfall over the forest, the cleared land, the hill and the valley, can only be successful in so far as we make due allowance for the influence of the wind and the character of the precipitation.

CHRONOLOGICAL VARIATIONS OF RAINFALL.

What has just been said with regard to geographical distribution holds good equally with regard to the chronological variations in rainfall. Undoubtedly there are years of large and of small precipitation, but if we analyze these years we shall see that they differ, not only in the quantity, but at the same time in the quality of the precipitation and in the forces of the winds. Until we are able to correct the measured rain or snow for the wind effect we must include this large source of uncertainty in the catalogue of errors to which our measurements are subject; thus, in some years, there may be a heavy snowfall of very light snow flakes falling during strong wind, and in spite of all our efforts to estimate we get too small a record. Again, if we confine ourselves to the summer rains only, namely, those that directly affect the growth of plants, we shall find that in almost every long-continued series of observations at any locality trees, houses, and other obstacles have gradually grown up in the neighborhood so that the average wind force at the gauge has undergone a steady progressive diminution and the gauge, therefore, catches a larger percentage at the close of the series than at the beginning, unless the obstacles were always so near as to shelter the gauges. I have computed the departure of each annual total precipitation (rain and snow) from the mean of forty-six years at Fort Leavenworth, Kans. (using post-surgeon's record only); of twenty-two years at Spiceland, Ind. (observations by H. R. Dawson), and forty-two years at Washington, D. C. (observations at the Naval Observatory). From the mean of these departures it is easy to compute

the so-called probable error or departure for any one year, or the index of variability of annual precipitation. The results are given in the accompanying Table VIII, and are interpreted in the following paragraph:

TABLE VIII.

Stations.	Number of years.	Average total annual precipitation.	Probable error of annual precipitation.		Probable error of mean of 49 years.	
		Inches.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*
Leavenworth	46	32.48	6.02	18	0.86	2.6
Spiceland	22	39.40	5.47	14	0.78	2.0
Washington	42	39.48	5.20	13	0.74	1.9

The mean annual catch at the Fort Leavenworth gauge is 32.48 inches, as given by 46 years of observations, which, however, differ among themselves from year to year so much that it is an even chance that the catch of any one year will differ from this mean by more or less than 18 per cent of its value or by 6.02 inches; this 18 per cent is in part due to actual irregularities in rainfall and in part to the variable effect of the wind and the irregular proportions of snow and rain; the actual rainfall is larger than this catch by an unknown amount depending on the character of the precipitation and the strength of the wind at mouth of the gauge.

It is therefore evident that any conclusion as to a change of climate during these years involving quantities less than the probable errors of the mean rainfall must be entirely illusory.

RECOMMENDATIONS.

Our study of the rain gauge (section 6) and its errors would have a melancholy conclusion did it not afford us some suggestion as to the proper methods of determining and allowing for these errors. In view of our present knowledge we now see that in establishing new stations better methods of exposure should be adopted and such as are in fact very different from those that have hitherto been considered allowable. We must closely imitate the conditions prevailing at the average surface of the ground, that is to say, in the order of preference the exposure would be: (1) the pit gauge; (2) the protected or the shielded gauge near the ground; (3) several protected or shielded gauges distributed over a flat roof; (4) the shielded gauge on posts considerably elevated above slanting roofs. Moreover, in no case should a single gauge be relied upon, but in all cases at least two similar gauges at very different heights should be observed. From the records of these two gauges we can compute the catch of the normal pit gauge by the formula previously given.

As this formula is also applicable to the ordinary and in fact any form of gauge, we furthermore see that an approximate correction, needed to reduce valuable past records to the normal gauge, may now be determined, if these old gauges are still being recorded, by at once establishing near them two or more similar gauges at considerably different heights; from the records of all these gauges for the next few years we may determine, at least approximately, a correction applicable to the past years of historical records. Finally, we are warned against attempting to draw from past records conclusions that are finer than the data will justify.

APPLICATION TO FORESTRY.

To this presentation of the rain-gauge question I will add that although the ideas here given may not be altogether new to those especially interested in rainfall, yet their application to the special precaution of establishing rain gauges in pairs at two different altitudes has only been carried out by Ebermayer in Bavaria, and more recently by Brandis and Blanford in the forests of the central provinces of India, but

I do not know that the formula for correction has as yet been used by them. Blanford placed his upper gauges at the height of 60 feet, *i. e.*, above the tree tops, and the lower ones at 1 foot. The result of his first year's observations showed that the high gauges in the forests gave 4 per cent more rain than the high ones in the open fields, a result entirely in accordance with the facts and views we have already presented; the gauges in the forests were at a height above the average tops of the foliage of the trees, decidedly less than the 90 feet by which the gauges in the open lands were elevated above the ground, therefore the high forest gauges should experience less wind and consequently catch more rain than the high open land gauges, while the average rainfall for the whole country averages the same. Again Blanford's low gauge gave 2 per cent greater catch in the forest than in the open land, a result also perfectly accordant with our views (Met. Zeit., 1888, v, p. 236) and serving to dissipate the last argument in favor of the idea that forests appreciably increase the rainfall as distinguished from the catch of the gauge.

The preceding study assumes that of the local pairs of gauges one at least is high enough to escape spattering from the ground, and this is easily attained in ordinary rains, but in the case of drifting snow this is difficult, and I will present my conclusions as to the correction for drift and spatter at some future time.

APPENDIX 2.

ANALYSIS OF THE CAUSES OF RAINFALL WITH SPECIAL RELATION TO SURFACE CONDITIONS.

By GEORGE E. CURTISS.

The possibility of changing the amount of rainfall by human agency has in late years received a great deal of popular attention, and an undercurrent of hypothesis with regard to it has gradually set in, which itself has stimulated scientific inquiry. The question has been directed most frequently to the effect of forests and to the special inquiry as to whether forestation increases and deforestation decreases the rainfall.

In this inquiry the statistical method has been extensively employed, and all the existing rainfall data bearing upon the question and some that are entirely irrelevant have been discussed. Special rainfall observations have also been inaugurated for the purpose of determining the relation of forests to rainfall. Without giving a résumé of these various investigations it is sufficient to state that no definitive conclusion has as yet been derived from them. The one conclusion which the statistical results seem to yield is that, if forests affect the rainfall the amount of effect has, in most cases, not been greater than the amount of probable error in the observations themselves, and, therefore, the statistics give no assurance that the effect is not an error of observation. This, however, is a result of importance, for it serves to delimit, for the regions to which the statistics apply, a maximum value which the supposed effect of forests has not exceeded. This maximum value is, in most cases, but a small fraction of the total rainfall, an amount too small to be of any considerable hydrographic or economic importance. Another reason for the unsatisfactory results of the statistical investigations is, that they have seldom been combined with a rational explanation of the process by which a change in the rainfall may be brought about, and, consequently, they have not helped to clarify the misty meteorological conceptions which are current thereon. To do this is the object of this paper.

If in any region the rainfall is increased by a forest cover it must be brought about either (1) by an increase in evaporation, which increase must be precipitated over the same region, or (2) by a diversion to the forest area of rain that would otherwise fall in some other locality.

Let us now analyse the causes and conditions of rainfall, so far as they are now understood, and see if the results will not materially aid us in determining how far and in what cases each of these methods of increasing the rainfall can be operative and efficient. I say in what cases, for one of the most important objects of this analysis will be to make clear that an effect that obtains in one climate may be entirely absent in another. Ideas as to the causes of rain have been greatly simplified by re-

cent studies, and many different conditions that are generally enumerated by the books as productive of rain have been set aside.

The following quotation, from a recent paper by Blandford, sets forth with great clearness the opinions that meteorologists are now adopting:

"As a result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain slopes, etc., are either inoperative or relatively insignificant." (Nature, XXXIX, 583).

The ascensional movement of the air requisite to dynamic cooling may be brought about by three different processes: (1) by convective currents; (2) by hills and mountains; (3) by cyclonic circulation; and I classify rainfall as convective, orographic, or cyclonic, according as it is due to the first, second, or third of these causes of ascensional movement. Of course in some cases all of these may be operative at the same time, but for the purposes of analysis they will be separately considered.

In a region of purely convective rainfall, the circulation is primarily vertical, and the moisture evaporated is largely precipitated before being carried away by horizontal currents. Therefore an increased evaporation will be followed by an increased rainfall. Consequently any change in surface condition which increases or diminishes the evaporation will, in such a climate, be followed by a corresponding increase or decrease in precipitation.

In the case of orographic rainfall, currents that are essentially horizontal are forced to become locally ascending. The moisture evaporated in the region lying in the path of the current is partially or entirely precipitated over the region where the ascensional movement is developed. Consequently an increased evaporation will, to a greater or less extent, be restored to the basin by an increased precipitation. The extent to which this will take place, that is, the proportion of the increase of moisture that will be returned to the basin, will depend on the extent and height of the mountains and the relative frequency of the orographic rain-bearing winds. For example, if these winds prevail only half of the time, only half of an increased evaporation can, in general, be precipitated as orographic rainfall. It seems quite possible, therefore, with observations showing the amount of change in the evaporation and with observations of the relative frequency of wind direction, to compute with considerable closeness a maximum value which the resulting change in rainfall can not exceed.

The second point to be considered with respect to orographic rainfall is whether a forested hill or mountain can originate or divert to itself moisture-laden currents which, without a forest cover, would not exist or would give their rain to other localities. Mountains, by means of their heated surfaces, develop upward currents, but when they are forest covered the observations presented by Mr. Fernow in this bulletin show that the air is less heated than when the surface is bare. Forests will, therefore, tend to diminish rather than to augment the diurnal currents which set in upwards toward the summit, and which, by dynamic cooling, precipitate their moisture. Likewise, there is lacking any sufficient reason to suppose that lateral currents moving in some other direction will more likely be deflected from their course and diverted toward this mountain summit because it is covered with forest and hence relatively cool.

The general class called cyclonic rainfall includes a great variety of rain types related to a cyclonic circulation, some of which are as yet by no means well understood.

In the ordinary progressive area of low pressure the cyclonic circulation is largely horizontal, but with an upward component. This upward component produces the usual rainfall of our cyclonic storms. In these storms the horizontal component of

the circulation is so large that the moisture evaporated over one region is precipitated over another. Consequently in regions where rainfall is of this type, an increased evaporation in any region will not be followed by an increased rainfall in that same locality.

In local thunder storms we have a type of rain related to a cyclonic circulation in which the vertical component often becomes very large, as compared with the horizontal component. This predominating vertical component is due to convection and the accompanying rainfall is to be considered as partly or largely convective. Convection induces and imitates a cyclonic circulation which may continue after the direct convective action has ceased. It becomes desirable, therefore, to separate the directly convective rainfall, whose amount can be locally increased by increase of evaporation, from the cyclonic rainfall whose amount can not be so increased. An approximate separation can be made when the diurnal periodicity of rain is known; for an excess of rainfall during the afternoon hours may be classed as convective.

Secondly, we have to consider the question as to whether cyclonic rain storms can be deflected from one course to another by difference in surface conditions. Evidently great areas of low pressure can not be affected and so the question is restricted to local cyclonic storms of small area. With respect to these the question is to be answered in the affirmative, for it is entirely in accord with physical principles to suppose that small cyclonic storms, areas of clouds and disturbance and other unsettled masses of air with a progressive motion, will tend to follow paths of high humidity and high temperature, lines of atmospheric weakness which all disturbances will seek, just as seismic disturbances follow lines of weakness in the earth's crust.

Whether the air over a forested area as compared with a neighboring unforested area constitutes such a preferable storm path is a question to which a dogmatic answer can not now be given. As shown by observation the absolute humidity is in general higher over the forest and the temperature lower than over adjacent open spaces. These are apparently conflicting conditions—one decreasing, the other increasing the relative density and stability of the forest air. It seems hardly probable that the resultant will have any quantitative importance. However, the investigation of the question is a fruitful direction of meteorological inquiry.

The practical point here to be emphasized is that it is not enough to say that the air over a forest is more humid and that therefore there will probably be more rainfall. The increased humidity will be quite ineffective unless this moist air can be cooled dynamically over the region itself, and thus condensed and precipitated. This is a necessary additional condition, and the evidence that this will occur in any relative high degree, either by convection currents or by deflected storm paths is yet lacking.

CLIMATIC ILLUSTRATIONS.

The equatorial rain belt is the most prominent region with almost exclusively convective rainfall. The Brazilian forest region, the Aruwhini district of central Africa, the Malaysian Archipelago, and the valley of Upper Assam in India are in or near this belt. They have light winds, and the moisture evaporated from the surface is precipitated before being carried to any considerable distance by horizontal currents. Under these conditions an increase or decrease in the evaporation will be followed by an increase or decrease in rainfall. But they are the very regions where any material change in the evaporation appears to be most difficult to effect.

The evaporation is large. Blanford estimated that for the Aruwhini district probably over half of the rainfall is due to the direct restoration of the moisture evaporated. The surface is maintained in a continual state of saturation and evaporation proceeds uninterruptedly at a nearly uniform rate. How will deforestation affect this evaporation? In the first place, a cleared surface will have a higher temperature, and the winds will have freer play, both of which results will conduce to

increase the evaporation, and, consequently, also to increase the rainfall. The wind effect, however, will be small because the regions under consideration are in the belt of calms. On the other hand, if deforestation should initially induce a materially increased run-off, so that there should be left much less water to evaporate, the evaporation would be diminished, and consequently also the rainfall would be diminished; and when the rainfall had fallen off the streams would fall to their previous quantity of discharge. We have, therefore, a possibility of two opposite tendencies acting at the same time—one to increase the rainfall, the other to decrease it. The question as to which will preponderate, and to what extent, is apparently a question to be ascertained for each separate district, for the result in one region may be quite different from what it will be in another. Furthermore, this analysis suggests that a very promising method of investigating the effect of forestation and deforestation in districts of convective rainfall appears to be not by observations of rainfall, but by comparative observations of the discharge of the streams. Finally, in the equatorial belt, which is the only portion of the world having an almost exclusively vertical circulation, the rainfall is so much in excess of the needs of vegetation that its possible modification has not the same economic importance as in higher latitudes. There is no motive to increase it, and if diminished no detriment would result.

Bordering on each side of the equatorial belt are the regions of the trades, which, over the ocean, are almost rainless; but over intercepting land areas, such as Central America and the Antilles, considerable rainfall occurs. This is frequently difficult to analyze, but it is largely convective and in hilly regions partly orographic. The seasonal distribution shows that the rainfall is intimately related to the annual oscillation of the limits of the trade wind, and that the rainy season requires a special explanation. With the exception of the well-known tropical cyclones of the seas, the distribution of pressure over the trade region is unfavorable to the development of a cyclonic circulation, and consequently cyclonic rainfall is seldom presented. It is easily seen that the application of this very general statement to the question of the effect of surface conditions requires us to consider some special individual locality. Let us take the island of Barbadoes. This island is 21 miles long, 14 miles across its widest part, and lies in latitude 13° N., longitude 59° 37′ W. Its interior is hilly and rises at points to over a thousand feet in height. From an extended series of rainfall records carried on by Governor Rawson the average rainfall on the coast is found to be 50 inches, and rising 64 inches on the windward side and in the central highlands. During three-fourths of the year the northeast trade wind prevails and the rain comes from that quarter. In October, when the southern limit of the trade reaches the island, the wind turns to the west and the heaviest rains occur, making it the wet season. The distribution of rain over the island, both with the trade wind and the west wind, shows that the rainfall is partly orographic, but probably the largest part of it must be considered as convective. On account of the smallness of the island and the prevailing fresh winds, practically all of the moisture thus precipitated on the island comes from the ocean, and the moisture evaporated from the island itself is carried away to sea. When the island was covered with forests the convective action of the island could not have been greater than at present, because its temperature would have been lower, and if a greater evaporation took place there no appreciable amount of the additional vapor could be precipitated on the island itself. We have every reason, therefore, to conclude that destruction of forests or any other service change in Barbados is powerless to sensibly increase or decrease its rainfall.

Passing from the region of trades, we reach latitudes favorable to cyclonic development. Here convective and cyclonic action are frequently combined. In the warmer latitudes and in the summer season, the equilibrium of the atmosphere becomes unstable and convection currents are set up which induce an incipient cyclonic circulation. Then there is a combined convective and cyclonic rainfall. As

we go northward the direct convective feature of the rainfall becomes less prominent, and the purely cyclonic rainfall predominates. Over the whole region orographic rainfall is added to the other two classes when hills or mountains are situated in the path of moisture-laden currents. With this general statement the further examination of the effect of surface conditions on the rainfall in middle latitudes must be applied to concrete cases.

In the United States the Great Plains region of Kansas, Nebraska, and the Dakotas is that for which a variation in rainfall has most often been claimed or anticipated. Many settlers believe that the so-called "rain belt" is moving rapidly westward with the extension of cultivation and settlement.

The single condition favorable to such an increase of rainfall consists in the steadier and larger evaporation which no doubt takes place over the cultivated area, but the other conditions necessary to condense and precipitate this moisture over the same region are largely absent. There are no hills or mountains to produce orographic rainfall, and without these barriers the high winds constantly carry away the moisture evaporated from the surface and precipitate it far to the eastward. Hence, not only is the increased moisture in the air but a small fraction of the total rainfall, but also only a small portion of this is gathered into convective or cyclonic currents and restored again by them to the prairie soil. Evidently a small amount must be thus restored in every summer rain and the total rainfall increased thereby, but quantitatively this must be very small.

There is one region deficient in rainfall and water supply for which claims in behalf of an actual or possible increase of rainfall due to human agency are less often made, but which the preceding analysis leads me to believe would not be unreasonable to anticipate. I refer to the San Joaquin Valley of California. This valley is flanked by the Coast Range on the west and by the Sierras on the east. The moisture evaporated from the surface can not escape from the basin, but will be largely precipitated either over the valley or on the sides of the adjacent mountains which constitute its watershed. If, therefore, the increase in irrigation and in the extent of cultivated area produces a material increase in the evaporation, it seems reasonable to expect that this moisture will be restored by an increased rainfall in the valley and in the adjacent mountain sides. One consideration only would appear to retard and diminish this effect. The inclosure of the valley prevents that rapid indraft of air which renders possible a rapid vertical circulation. Thus the activity of the whole process is rendered sluggish and the total amount of moisture passing through the cycle from evaporation to rainfall is smaller than with a more rapid circulation.

In the manner here outlined the possibility of a variation of rainfall may be investigated for any region, and with sufficient meteorological data even quantitative values may be computed. The general result indicated by the analysis of the physical processes involved as well as by the statistical data so far collected is that the margin of such possible change is very small. In most cases it can not exceed a small per cent, and in other cases it can not occur at all. It appears, therefore, that in the estimation of the importance and value of forests, a disproportionate and undue amount of emphasis has been popularly given to such an influence.

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